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(54) Apparatus for localization of sound image

(57) A sound image localization apparatus comprises crosstalk canceling means and direction localizing means, wherein first the crosstalk canceling means first subject an input sound signal to crosstalk cancellation, and then, the direction localizing means subject the processed signal to directional localization, whereby both crosstalk cancellation and directional localization share a signal to be processed, so the necessary amount of a storage device to hold the signal is reduced. That is, a reduction in circuit scale and calculation load can provide a sound image localization apparatus with low cost and high processing precision.

Descripti n

FIELD OF THE INVENTION

The present invention relates to an apparatus for localization of a sound image and, more particularly, to an apparatus for localization of a sound image which receives a sound signal, subjects the sound signal to signal processing, localizes a virtual sound image, and outputs a sound image localization signal.

BACKGROUND OF THE INVENTION

A conventional stereophonic system controls sound image localization using a plural of (generally two) loudspeakers, conferring a realistic sensation to the hearing of a listener. The conventional system usually includes two laterally spaced loudspeakers in front of the listener, so a sound image is localized between them. Outside the two loudspeakers no sound image is localized in the system. To obtain the effect that a sound image is localized outside the two loudspeakers, i.e., the surround of the listener, for instance, a sound from the back of the listener, the system sometimes includes loudspeakers at the rear as well as the two loudspeakers in front of the listener.

The development of technology for digitizing audio and hardware for DSP (Digital Signal Processor) facilitates various signal processing. Owing to this, the system using two loudspeakers in front of the listener can localize a sound image at any position around the listener, such as the side and rear of the listener.

The prior art sound image localization apparatus has been discussed in "A Study of Cancellation of Crosstalk Signal for Sound Field Control", Collective Papers of Spring Convention of Japanese Acoustical Society, 1996, pp 549-550 (hereinafter referred to as bibliography 1).

Figs. 19(a) and 19(b) are diagrams for explaining about sound image localization. Fig. 19(a) shows a sound image to be localized in a virtual way. Fig. 19(b) shows a system using two loudspeakers. In this case, it is assumed that the positions of virtually localized sound images, and the positions of the two loudspeakers are left-and-right symmetrical with respect to the listener.

In the sound image localization apparatus, a direction of a virtual position is localized and crosstalk is canceled by signal processing using a head related transfer function indicating transfer characteristics of sound from a sound source to the listener's head or ear.

Here, in case like Fig. 19(b), a crosstalk signal is a signal transferred from a left loudspeaker to a right ear, or from a right loudspeaker to a left ear. A signal is generated for canceling the crosstalk signal.

In the virtual environment achieved by this system as shown in Fig. 19(a), sound signals uL and uR are radiated from the positions of virtual sound images located laterally at the back of the listener. Reference numerals, yL1 and yR1, indicate sound pressures given to left and right ears, respectively. Because of the left-and-right symmetry, transfer of sound from the left virtual position to the left ear is the same as that from the right virtual position to the right ear. Ahead related transfer function showing this transfer characteristics is indicated by TM. The transfer of sound from the left virtual position to the right ear and that from the right virtual position to the left ear are represented by the same head related transfer function TC. The relation between the sound pressures and the functions are represented by

$$yL1 = TM \cdot uL + TC \cdot uR \qquad (1\text{-}1)$$

and

$$yR1 = TC \cdot uL + TM \cdot uR \qquad (1\text{-}2).$$

On the other hand, in a system shown in Fig. 19(b), left and right loudspeakers 1901a and 1901b radiate sound signals xL and xR, respectively. Sound pressures given to the left and right ears of the listener are yL2 and yR2, respectively. As they are left-and-right symmetrical, the transfer of sound from the left loudspeaker position to the left ear and that from the right loudspeaker position to the right ear are represented by the same head related transfer function SM. The transfer of sound from the left loudspeaker position to the right ear and that from the right loudspeaker position to the left ear are also represented by the same head related transfer function SC. The relation between those sound pressures and those functions are

$$yL2 = SM \cdot xL + SC \cdot xR \qquad (2\text{-}1)$$

and

$$yR2 = SC \cdot xL + SM \cdot xR \qquad (2\text{-}2).$$

In this system, to localize the positions of the sound images shown in Fig. 19(a) using acoustics output from the loudspeakers 1901a and 1901b, the following equations must be satisfied,

$$yL1 = yL2 \qquad (3\text{-}1)$$

and

$$yR1 = yR2 \qquad (3\text{-}2).$$

The equations 3-1, 1-1, and 2-1 lead to the following equation 4-1, and the equations 3-2, 1-2, and 2-2 lead to the following equation 4-2,

$$TM \cdot uL + TC \cdot uR = SM \cdot xL + SC \cdot xR \qquad (4\text{-}1)$$

and

$$TC \cdot uL + TM \cdot uR = SC \cdot xL + SM \cdot xR \qquad (4\text{-}2).$$

The solution to xL and xR is obtained from the equations 4-1 and 4-2. If assumed that, the gain being represented by |*|,

$$|(SC/SM)^2| << 1 \ (5),$$

xL and xR are approximated by

$$xL \sim (FM + FC \cdot FX) \cdot uL + (FC + FM \cdot FX) \cdot uR \qquad (6\text{-}1)$$

and

$$xR \sim (FC + FM \cdot FX) \cdot uL + (FM + FC \cdot FX) \cdot uR \qquad (6\text{-}2),$$

where

$$FM = TM/SM \qquad (7\text{-}1),$$

$$FC = TC/SM \qquad (7\text{-}2),$$

and

$$FX = -SC/SM \qquad (7\text{-}3).$$

The other solution is possible, that is,

$$xL = FM \cdot uL + FC \cdot uR + FX \cdot xR \qquad (8\text{-}1)$$

and

$$xR = FC \cdot uL + FM \cdot uR + FX \cdot xL \qquad (8\text{-}2)$$

are obtained. In the equations 8-1 and 8-2, the first and second terms on the right side indicate the directions of sound images, that is, they localize the directions. The third term on the right side cancels a crosstalk component.

Using the above relations, a conventional sound image localization apparatus is constructed, shown in Fig. 17(a). The conventional sound image localization apparatus comprises a crosstalk canceling means 1701, direction localizing means 1702a and 1702b, and adders 1703a and 1703b. Sound signals are input through input terminals 1704a and 1704b. Signals resulting from subjecting the input sound signals to signal processing are output through output terminals 1705a and 1705b.

The direction localizing means 1702a and 1702b process the sound signals input through the input terminals 1704a and 1704b to generate signals indicating the directions of sound image positions, respectively. The adders

1703a and 1703b add input signals. The crosstalk canceling means 1701 removes a crosstalk component of an input signal.

Fig. 17(b) is a diagram illustrating an example of detailed structure of the conventional sound image localization apparatus. The crosstalk canceling means 1701 shown in Fig. 17(a) comprises crosstalk canceling signal generating filters 1706a and 1706b, and adders 1703c and 1703d. The direction localizing means 1702a and 1702b shown in Fig. 17(a) comprise main-path filters 1707a and 1707b, and crosstalk-path filters 1708a and 1708b, respectively. The combination of the main-path filter and the crosstalk-path filter is sometimes called a direction localizing filter.

The prior art sound image localization apparatus generates the outputs xL and xR according to the expressions 6-1 and 6-2. A description will be given of how the sound image localization apparatus works.

Left and right input sound signals are input through the input terminals 1704a and 1704b, respectively. The first input sound signal input through the input terminal 1704a is input to the main-path filter 1707a and the crosstalk-path filter 1708a. The main-path filter 1707a multiplies the input signal by the coefficient shown in the equation 7-1. The crosstalk-path filter 1708a multiplies the input signal by the coefficient shown in the equation 7-2. The outputs of the main-path filter 1707a and the crosstalk-path filter 1708a are input to the adders 1703a and 1703b, respectively.

Similarly, the second input sound signal input through the input terminal 1704b is input to the main-path filter 1707b and the crosstalk-path filter 1708b, where the input signal is multiplied by the coefficients expressed by 7-1 and 7-2, respectively. The outputs of the main-path filter 1707b and the crosstalk-path filter 1708b are input to the adders 1703b and 1703a, respectively.

The adders 1703a and 1703b each add input signals. The adder 1703a outputs a result of the addition to the adder 1703c and the crosstalk canceling signal generating filter 1706a. The crosstalk canceling signal generating filter 1706a multiplies the input signal by the coefficient represented by the equation 7-3 to produce a crosstalk canceling signal signal, and outputs the signal to the adder 1703d.

Similarly, the adder 1703b outputs a result of the addition to the adder 1703d and the crosstalk canceling signal generating filter 1706b. The crosstalk canceling signal generating filter 1706b multiplies the input signal by the coefficient represented by the equation 7-3 to produce a crosstalk canceling signal, and outputs the signal to the adder 1703c.

The adders 1703c and 1703d each add results of addition by the adders 1703a and 1703b to the crosstalk canceling signal having phase almost equivalent to the inversed phase of the result of the addition, respectively. Thus, signals represented by the expressions 6-1 and 6-2, of which crosstalk components are removed, are output through the output terminals 1705a and 1705b, respectively.

In the sound image localization apparatus having the structure shown in Fig. 17(b), the output of a crosstalk canceling signal generating filter on either channel (for example, 1706a) is output to the output side of the other channel (the adder 1703d on the side having the output terminal 1705b). This structure is called feedforward.

Disclosed is an apparatus, which is a second example realizing the conventional sound image localization apparatus, in Japanese Patent Published Application No. Hei 9-233599 (1997) (hereinafter referred to as bibliography 2).

Fig. 18 is a diagram showing a detailed structure of a second example of the sound image localization apparatus. The crosstalk canceling means 1701 in Fig. 17(a) comprises crosstalk canceling signal generating filters 1806a and 1806b, and adders 1803a and 1803b. The direction localizing means 1702a and 1702b in Fig. 17(a) comprise main-path filters 1807a and 1807b, and crosstalk-path filters 1808a and 1808b, respectively. The adders 1803a and 1803b are the same as the adders 1703a and 1703b in Fig. 17(a), and also part of the crosstalk canceling means 1701.

The sound image localization apparatus shown in Fig. 18 generates outputs xL and xR according to the equations 8-1 and 8-2. With the different structure from that shown in Fig. 17(b), the sound image localization apparatus is called a feedback type, because a crosstalk canceling signal generating filter (for instance, 1806a) on either channel outputs a signal to the input side on the other channel (the adder 1803b). A description will be given of how the sound image localization apparatus operates.

Left and right input sound signals are input through the input terminals 1804a and 1804b, respectively. The first input sound signal input through the input terminal 1804a is input to the main-path filter 1807a and the crosstalk-path filter 1808a. The main-path filter 1807a multiplies the input signal by the coefficient represented by the equation 7-1, and outputs the result to the adder 1803a. The crosstalk-path filter 1808a multiplies the input signal by the coefficient represented by the equation 7-2, and outputs the result to the adder 1803b. In a similar way, the right input sound signal input through the input terminal 1804b is input to the main-path filter 1807b and the crosstalk-path filter 1808b, where the signals are multiplied by coefficients represented by the equations 7-1 and 7-2, and the results are output to the adders 1803b and 1803a, respectively.

The adders 1803a and 1803b each add the input signals. The adder 1803a outputs a result of the addition to the crosstalk canceling signal generating filter 1806a. The crosstalk canceling signal generating filter 1806a multiplies the input signal by the coefficient represented by the equation 7-3 to generate a crosstalk canceling signal, and outputs it to the adder 1803b. Similarly, the adder 1803b outputs a result of the addition to the crosstalk canceling signal generating filter 1806b. The crosstalk canceling signal generating filter 1806b multiplies the input signal by the coefficient rep-

resented by the equation 7-3 to generate a crosstalk canceling signal, and outputs it to the adder 1803a.

The adders 1803a and 1803b add the outputs of the direction localizing filter, and further add a result of the addition to the crosstalk canceling signal having phase almost equivalent to the inversed phase of the result of the addition, to remove a crosstalk component. Hence, signals represented by the equations 8-1 and 8-2 are output through the output terminals 1805a and 1805b.

As hereinbefore described, in the sound image localization apparatus in accordance with the first embodiment, multiple cancellation, in which the generation of a crosstalk canceling signal and the crosstalk cancellation using the generated signal are repeated, becomes possible. Compared with the first example, i.e., the feedforward type apparatus shown in Fig. 17(a), the adverse effect of sound diffraction of a low-frequency component of a sound signal is reduced, thereby solving the first problem of the prior art and improving low-frequency characteristics.

As described above, the conventional sound image localization apparatus can localize a sound image over a wide range by localization of a virtual sound image and compensation of a crosstalk component. However, when trying to realize the foregoing sound image localization apparatus by a computer system using a CPU and a DSP, the following several problems arise.

The first problem is about a memory used for temporary storage in operational processing. The amount and performance of a memory in a computer system limit operational processing. The main constraints on memory are

(A) constraint on the amount of memory for storage of sound signal data,
(B) constraint on the amount of memory for storage of coefficients of a filter, and
(C) constraint on accessing time of a memory.

As to (A) and (B), when the number of words showing the amount of memory is small, the number of taps indicating the order of a filter is limited to an insufficient size, resulting in a reduction in precision of operational processing.

Furthermore, when the amount of a high-speed internal memory included in a computer system is limited, if a relatively low-speed external memory (RAM) assists to secure a required precision of operational processing, the problem (C) arises. Because frequent memory accesses occur in operational processing realizing the above-described digital filter performing directional localization and crosstalk cancellation, a simple supplement of the external memory having a low accessing speed hardly solves the constraint on the amount of memory.

The second problem relates to a controller included in a computer system, such as DSP. The processing speed of the controller limits operational processing. When the processing speed is not sufficient, the order of a digital filter is limited, thereby reducing precision in operational processing.

The third problem is that it is difficult for the conventional sound image localization apparatus to deal with changes in setting of an acoustic system using it. The second example of the prior art sound image localization apparatus shown in Fig. 18, i.e., the feedback type, improves the reproducibility of a low-frequency component compared with the feedforward type. However, when a loudspeaker with a small diameter is used in an acoustic system to which the sound image localization apparatus is applied, the large energy of the low-frequency range causes sound distortion. If a filter cutting off a low-frequency component is adopted to improve this point, the additional filter increases the circuit scale and the cost.

Further, when loudspeakers are rearranged in the acoustic system in such a way as that the angle the loudspeakers attain changes, the conventional sound image localization apparatus modifies all the parameters of the filter FX. Thus, to adapt to changes in setting of the acoustic system, parameters for each setting are required to be held. The requirement of storage of parameters increases the amount of memory.

As the three problems indicate, the prior art sound image localization apparatus has a difficulty in improving low-frequency characteristics. Furthermore, when implemented in a computer system, the apparatus requires the large amount of memory and the high-speed of processing, thereby making it difficult to realize both precision of controlling sound image localization and a reduction in costs of the computer system.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision while limiting an increase in the circuit scale caused by requirement of the amount of memory.

It is another object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision by additionally exploiting an external memory when the amount of a high-speed internal memory is limited.

It is still another object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision by simplifying operational processing when the computer system does not include a high-performance DSP.

It is yet another object of the present invention to provide a sound image localization apparatus flexibly coping with changes in setting of the acoustic system, without increasing the circuit scale.

Other objects and advantages of the present invention will become apparent from the detailed description desired hereinafter; it should be understood, however, that the detailed description and specific embodiment are desired by way of illustration only, since various changes and modifications within the scope of the invention will become apparent to those skilled in the art from this detailed description.

According to a second aspect of this invention, there is provided the sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for generating a crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
direction localizing means for localizing the direction of a virtual sound source position by processing the signal subjected to crosstalk cancellation in the crosstalk canceling means.

As a result, the apparatus first performs crosstalk cancellation to an input sound signal, and then, performs directional localization to the sound signal.

According to a second aspect of this invention, there is provided the sound image localization apparatus of the first aspect wherein

the crosstalk canceling means comprise first and second crosstalk canceling signal generating filters, and first and second adders, the first adder adding a first sound signal and a signal generated by the second crosstalk canceling signal generating filter, and the second adder adding a second sound signal and a signal generated by the first crosstalk canceling signal generating filter;
the direction localizing means comprise first and second main-path filters, first and second crosstalk-path filters, and first and second adders, the first adder adding a signal processed by the first main-path filter and a signal processed by the second crosstalk-path filter, and the second adder adding a signal processed by the second main-path filter and a signal processed by the first crosstalk-path filter.

As a result, the apparatus first performs crosstalk cancellation to an input sound signal using a signal generated by a crosstalk canceling signal generating filter, and then, performs directional localization to the sound signal using a main-path filter and a crosstalk-path filter.

According to a third aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for including a comb filter to generate the crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation using a signal generated by a crosstalk canceling signal generating filter including a comb filter of which the coefficients are the same.

According to a fourth aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for generating a crosstalk canceling signal generated at a certain time, holding the crosstalk canceling signal, delaying the crosstalk canceling signal held, holding the plurality of crosstalk canceling signals delayed, and multiplying some of the plurality of crosstalk canceling signals held by a predetermined coefficient to generate the crosstalk canceling signal at a time following the certain time; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation using a singal generated a crosstalk canceling signal generating filter including a circuit replacing a comb filter, of which the processing load is reduced.

According to a fifth aspect of this invention, there is provided the sound image localization apparatus of any of the third and fourth aspects wherein

the apparatus further comprises a low-pass filter processing a signal input to or output from the crosstalk canceling

means.

As a result, the apparatus performs crosstalk cancellation to a signal, of which a high-frequency component is removed, using a singal generated a crosstalk canceling signal generating filter including a comb filter or a circuit replacing a comb filter.

According to a sixth aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a switch switching the crosstalk canceling signal generated by the crosstalk canceling signal generating filter to the output side of the crosstalk canceling signal generating filter or to the input side of the crosstalk canceling signal generating filter; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus switches feedback processing and feedforward processing.

According to a seventh aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a delaying unit delaying a signal input to or output from the crosstalk canceling signal generating filter by various times; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation by changing the amount of an initial delay.

According to an eighth aspect of this invention, there is provided a sound image localization apparatus receiving an input sound signal to be localized in a first direction, and an input sound signal to be localized in a second direction, performing signal processing to the input sound signals, localizing virtual sound images, and outputting sound image localization signals, the apparatus comprising:

crosstalk canceling means comprising a first filter, a second filter, and a switch switching first and second modes; in the first mode the first filter functioning as a filter generating the crosstalk canceling signal, and in the second mode the second filter functioning as a filter generating the crosstalk canceling signal while the first filter functioning as a filter localizing the second direction; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, a crosstalk canceling signal generating filter for localizing a sound image to be localized in a first direction, and a crosstalk canceling signal generating filter for localizing a sound image to be localized in a second direction, are switched.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1(a) and 1(b) are block diagrams showing structures of a sound image localization apparatus in accordance with a first embodiment of this invention.
Fig. 2 is a diagram showing an example of a structure of a filter included in the sound image localization apparatus of the first embodiment.
Fig. 3 is a diagram showing an example of a structure of a filter included in the sound image localization apparatus of the first embodiment.
Fig. 4 is a block diagram showing a structure of an application example of the sound image localization apparatus of the first embodiment.
Fig. 5 is a block diagram showing a structure of a sound image localization apparatus in accordance with a second embodiment of this invention.
Fig. 6 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.
Figs. 7(a) and 7(b) are graphs showing frequency characteristics of a filter used in the second embodiment to explain how the filter works.
Fig. 8 is a block diagram showing a structure of an application example of the sound image localization apparatus

of the second embodiment.

Fig. 9 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.

Fig. 10 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.

Fig. 11 is a block diagram showing a structure of a sound image localization apparatus in accordance with a third embodiment of this invention.

Fig. 12 is a block diagram showing a structure of a sound image localization apparatus in accordance with a fourth embodiment of this invention.

Fig. 13 is a block diagram showing a structure of an application example of the sound image localization apparatus of the fourth embodiment.

Fig. 14 is a block diagram showing a structure of an application example of the sound image localization apparatus of the fourth embodiment.

Fig. 15 is a block diagram showing a structure of a sound image localization apparatus in accordance with a fifth embodiment of this invention.

Fig. 16 is a block diagram showing a structure of a sound image localization apparatus in accordance with a sixth embodiment of this invention.

Figs. 17(a) and 17(b) are block diagrams showing structures of a first example of a prior art sound image localization apparatus.

Fig. 18 is a block diagram showing a structure of a second example of a prior art sound image localization apparatus.

Figs. 19(a) and 19(b) are diagrams for explaining sound image localization.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Embodiment 1]

A sound image localization apparatus in accordance with a first embodiment of this invention reduces the necessary amount of memory by subjecting a signal to directional localization after performing crosstalk cancellation to the signal.

Fig. 1(a) is a block diagram showing a structure of the sound image localization apparatus of the first embodiment. As shown in the figure, the sound image localization apparatus comprises a crosstalk canceling means 101, and direction localizing means 102a and 102b, adders 103a and 103b. The apparatus receives input sound signals through input terminals 104a and 104b, subjects the input signals to signal processing, and outputs the resulting signals through output terminals 105a and 105b.

The crosstalk canceling means 101 removes crosstalk components from the input signals input through the input terminals 104a and 104b. The direction localizing means 102a and 102b process input sound signals to produce signals indicating the directions of sound images. The adders 103a and 103b add input signals.

The operational processing of the sound image localization apparatus will be explained. Initially, in addition to the equations 1-1 to 8-2 shown in the BACKGROUND OF THE INVENTION and Embodiment 1 sections, vL and vR are defined by

$$xL = FM \cdot vL + FC \cdot vR \tag{9-1}$$

and

$$xR = FC \cdot vL + FM \cdot vR \tag{9-2}$$

Th equation 9-1 is substituted to the equation 8-1, and 9-2 is substituted to 8-2, and then

$$FM \cdot vL + FC \cdot vR = FM \cdot uL + FC \cdot uR + FX \cdot (FC \cdot vL + FM \cdot vR) \tag{10-1}$$

and

$$FC \cdot vL + FM \cdot vR = FC \cdot uL + FM \cdot uR + FX \cdot (FM \cdot vL + FC \cdot vR) \tag{10-2}$$

are obtained. From 10-1 and 10-2, FM and FC are eliminated, and then

$$vL = uL + FX \cdot vR$$

and

$$vR = uR + FX \cdot vL \qquad (11\text{-}2)$$

are obtained.

The equations 11-1 and 11-2 mean that a crosstalk canceling means is required to be set up on the input side. The equations 9-1 and 9-2 mean that direction localizing means are required to be set up on the output side. Accordingly, the sound image localization apparatus of the first embodiment, as shown in Fig. 1(a), includes a crosstalk canceling means 101 on the input side, and direction localizing means 102a and 102b on the output side.

Fig. 1(b) is a diagram showing a detailed structure of a first example of the sound image localization apparatus of the first embodiment. The crosstalk canceling means 101 shown in Fig. 1(a) comprises crosstalk canceling signal generating filters 106a and 106b, and adders 103c and 103d in Fig. 1(b). The direction localizing means 102a and 102b shown in Fig. 1(b) comprise main-path filters 107a and 107b, and crosstalk-path filters 108a and 108b in Fig. 1(b), respectively. An explanation will be given of the operation of the first example of the sound image localization apparatus.

Left and right input sound signals uL and uR are input through input terminals 104a and 104b. In Fig. 1(b), the first input sound signal uL input through the input terminal 104a is input to the adder 103c. The right input sound signal uR input through the input terminal 104b is input to the adder 103d. Immediately after the sound image localization apparatus starts processing, the crosstalk canceling signal generating filters 106a and 106b don't generate any signals to be output to the adders 103c and 103d, so the adders 103c and 103d output input signals uL and uR as they are. The signals uL and uR are input to the crosstalk canceling signal generating filters 106a and 106b as signals vL and vR, respectively.

The crosstalk canceling signal generating filter 106a multiplies the input signal by the coefficient having a negative sign represented by the equation 7-3 to produce a crosstalk canceling signal, and outputs it to the adder 103d. The crosstalk canceling signal generating filter 106b performs a similar processing to produce a crosstalk canceling signal, and outputs it to the adder 103c.

The adder 103c adds the input sound signal uL and the crosstalk canceling signal to perform crosstalk cancellation, generating the signal vL represented by the equation 11-1. The generated signal vL is input to the main-path filter 107a and the crosstalk-path filter 108a. In a similar manner, the adder 103d generates the signal vR represented by 11-2, which is input to the main-path filter 107b and the crosstalk-path filter 108b.

The main-path filter 107a multiplies the input signal by the coefficient represented by the equation 7-1, and outputs the result to the adder 103a. The crosstalk-path filter 108a multiplies the input signal by the coefficient represented by the equation 7-2, and outputs the result to the adder 103b. The output of the main-path filter 107a is represented by the first term on the right side of the equation 9-1. The output of the crosstalk-path filter 108a is represented by the second term on the right side of the equation 9-2.

Similarly, the adder 103d adds the crosstalk canceling signal to the input sound signal uR to perform crosstalk cancellation. The resulting signal vR is input to the main-path filter 107b and the crosstalk-path filter 108b, where the signal is multiplied by the coefficients represented by the equations 7-1 and 7-2, respectively. The outputs of the main-path filter 107b and the crosstalk-path filter 108b are input to the adders 103b and 103a, respectively. The output of the main-path filter 107b is represented by the first term on the right side of the equation 9-2. The output of the crosstalk-path filter 108a is represented by the second term on the right side of the equation 9-1.

The adders 103a and 103b each add input signals, and output results of the addition through the output terminals 105a and 105b, respectively. Thus, the sound image localization apparatus in accordance with the first embodiment outputs signals xL and xR processed by directional localization, represented by the equations 9-1 and 9-2.

As described above, in the sound image localization apparatus in accordance with the first embodiment, because signals are subjected to crosstalk cancellation prior to directional localization, as shown in Fig. 1(b), the inputs of the crosstalk canceling signal generating filter (FX) and the direction localizing filter (FM and FC) are the same signal, vL or vR. Thus, for filtering, just those two signals are required to hold. Compared with the conventional sound image localization apparatus shown in Figs. 17(b) and 18, required to hold four kinds of signals, the amount of memory required to hold sound signals, described as the first problem in the BACKGROUND OF THE INVENTION section, can be reduced to a small size.

To explain the required amount of memory in the apparatus of the first embodiment, each structure of filters for crosstalk cancellation and directional localization will be shown.

There are two sorts of filters, FIR (Finite Impulse Response) accumulating input signals and IIR (Infinite Impulse Response) accumulating output signals as well as input signals. Either of the two kinds of filters can realize the sound image localization apparatus of the first embodiment. Fig. 2 is a diagram showing the first example of the apparatus in which the crosstalk canceling signal generating filters 106a and 106b, and the direction localizing filters 107a, 107b,

108a, and 108b are FIR filters. Fig. 2 shows another example in which each filter shown in Fig. 1(b) is the concatenation of an FIR filter and an IIR filter.

In Fig. 2, the crosstalk canceling signal generating filter 106a included in the first example (Fig. 1(b)) of the sound image localization apparatus, comprises delaying units 111a and 111c to 111f, multiplier 110x1 to 110x5, and an adder 103i. The crosstalk canceling signal generating filter 106b comprises delaying units 111b and 111g to 111j, multipliers 110x6 to 110x10, and an adder 103j. The parts in Fig. 2 represented by the dashed lines, such as the multipliers 110x1 to 110x5 and the delaying units 111c to 111f, show that the number of multipliers or delaying units is variable.

The main-path filter 107a comprises delaying units 111c to 111f, multipliers 110m1 to 110m5, and an adder 103e. The main-path filter 107b comprises delaying units 111g to 111j, multipliers 110m6 to 110m10, and an adder 103f. The crosstalk-path filter 108a comprises delaying units 111c to 111f and 111n to 111p, multipliers 110c1 to 110c5, and an adder 103g. The crosstalk-path filter 108b comprises delaying units 111g to 111j and 111k to 111m, multipliers 110c6 to 110c10, and an adder 103h.

Multipliers 110a1 and 110a2 function as attenuators to prevent overflow in executing fixed point calculation. Delaying units 111k to 111p are employed to produce the time difference between both ears.

As the filters in Fig. 2 include the delaying units 111c to 111j, the crosstalk canceling signal generating filer and the direction localizing filter receive the same input signals, as signals vL or vR shown in Fig. 1(b). Hence, compared with the case where the input of each filter is held, it is possible to reduce the amount of memory required to hold signals.

Fig. 2 shows the example using IIR filters. In this example, a crosstalk canceling signal generating filter comprises IIR filter FXIs 112a and 112b. A main-path filter comprises IIR filter FMIs 113a and 113b. A crosstalk-path filter comprises IIR filter FCIs 114a and 114b. Those IIR filters are concatenated with the FIR filters shown in Fig. 2.

Th portions of the main-path filter, the crosstalk-path filter, and the crosstalk canceling signal generating filter, constituted by FIR filters, are represented by FMF, FCF, and FXF, respectively. The FM, FC, and FX shown in the equations 7-1 to 7-3 are represented by

$$FM = FMF \cdot FMI \tag{12-1}$$

,

$$FC = FCF \cdot FCI \tag{12-2}$$

,

and

$$FX = FXF \cdot FXI \tag{12-3}$$

.

Also in this case, similar to the structure shown in Fig. 2, the FIR filter portions share an input, thereby making it possible to reduce the required amount of memory. It should be noted that the reduction is not as much as that in the case where only the FIR filters are employed.

Fig. 4 is a diagram illustrating a second example of a detailed structure of a sound image localization apparatus, shown in Fig. 1(a), in accordance with the first embodiment. As shown in the figure, the second example of the sound image localization apparatus comprises adders 103a to 103d, crosstalk canceling signal generating filters 106a and 106b, main-path filters 107a and 107b, crosstalk-path filters 108a and 108b, high-frequency main-path filters 117a and 117b, subsampling circuits 115a and 115b, and band compositing circuits 116a and 116b. As in the first example shown in Fig. 1(b), input sound signals are input through the input terminals 104a and 104b, and subjected to signal processing, and the resulting signals are output through the output terminals 105a and 105b.

The subsampling circuits 115a and 115b subject input signals to prescribed subsampling to produce a low-frequency component and a high-frequency component. The band compositing circuits 116a and 116b subject input signals to prescribed composition to produce composite signals. The high-frequency main-path filters 117a and 117b operate in a similar way to the main-path filters 107a and 107b. The adders 103a to 103d, the crosstalk canceling signal generating filters 106a and 106b, main-path filters 107a and 107b, and the crosstalk-path filters 108a and 108b are similar to those in the first example.

The operation of the second example of the sound image localization apparatus of the first embodiment will be described.

L ft and right input sound signals are input through the input terminals 104a and 104b. The first input sound signal input through the input terminal 104a is input to the subsampling circuit 115a. The subsampling circuit 115a subsamples the first input sound signal to a high-frequency component and a low-frequency component, and outputs the high-frequency component to the high-frequency main-path filter 117a, and the low-frequency component to the adder 103c. The subsampling circuit 115b operates in a similar way.

The high-frequency main-path filters 117a and 117b multiply the input high-frequency components by the coefficient represented by the equation 7-1, and output the resulting signals to the band compositing circuits 116a and 116b, respectively.

The low-frequency component of the input sound signal is subjected to crosstalk cancellation and directional localization in a similar manner to the first example, and the resulting signals are input to the band compositing circuits 115a and 115b, respectively. The band compositing circuits 115a and 115b composite a signal resulting from processing the high-frequency component with the high-frequency filter, and a signal resulting from processing the low-frequency component by directional localization after crosstalk cancellation, and output the composite signals through the output terminals 105a and 105b, respectively.

As is clear from the above, a second example of the sound image localization apparatus subjects only the low-frequency component of the input signal to crosstalk cancellation. In general, the high-frequency component of an input signal is seriously affected by a slight shift of the head of a listener and differences among individuals, so that the benefit of crosstalk cancellation is little for the high-frequency component. Therefore, a second example of the sound image localization apparatus processes the high-frequency component only with the main-path filter. Thus, because the target of crosstalk cancellation is only the low-frequency component, the number of sampling frequency can be reduced, thereby making it possible to make the sizes of filter circuits in Figs. 3 and 4 smaller without reducing the precision of sound image localization.

As hereinbefore pointed out, the sound image localization apparatus in accordance with the first embodiment, as shown in Fig. 1(a), comprises a crosstalk canceling means 101 on the input side, and direction localizing means 102a and 102b on the output side. Thereby, each filter included in the crosstalk canceling means 101 and the direction localizing means 102a and 102b shares an input signal by using delaying units as shown in Figs. 2 and 3. As a result, the amount of memory required to hold a sound signal is reduced while sound image localization can be satisfactory.

[Embodiment 2]

A sound image localization apparatus in accordance with a second embodiment of this invention employs a comb filter.

Fig. 5 is a block diagram showing a structure of a first example of the sound image localization apparatus of the second embodiment. The outline of the structure of the sound image localization apparatus is similar to the structure of the feedback type apparatus in the prior art shown in Fig. 18. As shown in Fig. 5, the sound image localization apparatus comprises adders 503a, 503b, 503e, and 503f, main-path filters 507a and 507b, crosstalk-path filters 508a and 508b, delaying units 511a to 511j, and multipliers 510x1 to 510x10. Input sound signals are input through input terminals 504a and 504b, and subjected to signal processing, and the resulting signals are output through output terminals 505a and 505b. As in Fig. 2 and so on, dashed lines on rows of the delaying units and the multipliers represent an arbitrary number of the delaying units and the multipliers in Fig. 5.

In Fig. 5, the crosstalk canceling signal generating filter 106a shown in Fig. 18 comprises the delaying units 511a, 511c to 511f, the multipliers 510x1 to 510x5, and the adder 503e. The crosstalk canceling signal generating filter 106b shown in Fig. 18 comprises the delaying units 511b, 511g to 511j, the multipliers 510x6 to 510x10, and the adder 503f. All the coefficients of the multipliers 510x1 to 510x10 are possible to be the same, which makes the filter a comb type. Therefore, when using a comb filter, it is possible to reduce the amount of memory, required to hold the coefficient, described in the BACKGROUND IN THE INVENTION section, as the first problem (B).

The operation of the sound image localization apparatus of the second embodiment is similar to that of the feedback type sound image localization apparatus of the first embodiment.

Figs. 7(a) and 7(b) are graphs for explaining frequency characteristics of a filter. Fig. 7(a) shows amplitude characteristics. Fig. 7(b) indicates phase characteristics. In either figure, a solid line represents characteristics of the comb filter used in the second embodiment, and a dashed line represents characteristics obtained from the ratio of head related transfer functions. In general, a comb filter has linear phase type low-pass characteristics. As is apparent from the figure, both the characteristics are similar to each other in a low-frequency range of the amplitude and phase characteristics. As described in the first embodiment, cancellation is particularly effective in a low-frequency range of a sound signal. Because the characteristics of the comb filter is approximate to that obtained from the head related transfer function in the low-frequency range, the comb filter operates well for the low-frequency range. For a high-frequency range in which the two characteristics differ, crosstalk cancellation is hardly effective, so the influence of differences between the two characteristics is little.

Fig. 6 is a block diagram showing a structure of a second example of the sound image localization apparatus of the second embodiment. As shown in Fig. 6, this example includes a first example of the sound image localization apparatus, and further comprises low-pass filters 620a and 620b. The low-pass filter 620a comprises an adder 603c, multipliers 610f1 and 610f2, and a delaying unit 611a. The low-pass filter 620b comprises an adder 603d, multipliers 610f3 and 610f4, and a delaying unit 611b.

As to the operation of the sound image localization apparatus, the high-frequency components of signals input to the crosstalk canceling signal generating filters 106a and 106b shown in Fig. 18 are removed, and the other operation is similar to that of the first example. As hereinbefore pointed out, in generating a crosstalk canceling signal, the high-

frequency component of a sound signal is not necessarily taken into consideration. In this example, the high-frequency component is not the target of processing, thereby making it possible to improve the precision of sound localization better than the first example. Note that the scale of the circuit of the second example becomes slightly larger than that of the first example by the low-pass filter.

Although in the second example the low-pass filter is disposed in front of the crosstalk canceling signal generating filter, i.e., on the input side, the low-pass filter can be disposed at the rear of the crosstalk canceling signal generating filter, i.e., on the output side, thereby making possible the same effect.

Fig. 8 is a diagram showing a structure of a third example of the sound image localization apparatus of the first embodiment. As shown in the figure, this example employs a comb filter, similar to that in the first example, but having FIRs of which the number of taps is small. In the structure shown in Fig. 8, the number of taps is two, and all the coefficients can be set to, for instance, -0.46. In this case, the filter becomes a filter having linear phased low-pass characteristics. This sound image localization apparatus operates in a similar way to the first example.

In an acoustic system using the sound image localization apparatus, when the distance between two loudspeakers is set to be short, for example, the angle the loudspeakers attain is 10 to 20 degrees, the ratio of head related transfer functions shown in Fig. 19(b), i.e., SC/SM, becomes close to 1. Therefore, considering the stability of sound image localization, and a reduction in a high-frequency component due to the sound diffraction of a sound signal, a filter having a small number of taps has good approximation in this case. In the case, the apparatus having the structure shown in Fig. 8 can reduces the amount of memory required to store the coefficient further than the first example shown in Fig. 5. As a result, the amount of data held by the delaying unit becomes small, and it is possible to make the scale of the circuit smaller.

Figs. 9 and 10 are diagrams showing a structure of a fourth example of the sound image localization of the second embodiment. As shown in Fig. 9, this example of the sound image localization apparatus includes a third example of the apparatus, and further comprises high-frequency main-path filters 917a and 917b, subsampling circuits 915a and 915b, and band compositing circuits 916a and 916b. These are similar to those shown in the second example of the first embodiment, i.e., the high-frequency main-path filters 117a and 117b, the subsampling circuits 115a and 115b, and the band compositing circuits 116a and 116b. The same with high-frequency main-path filters 1017a and 1017b, subsampling circuits 1015a and 1015b, and band compositing circuits 1016a and 1016b, shown in Fig. 10.

As to the operation of this example of the sound image localization apparatus, subsampling and band composition are similar to those in the first embodiment, and the other processes are similar to those in the second embodiment. Therefore, similar to the second example in the first embodiment and the third example in the first embodiment, this example of the sound image localization apparatus can reduce the required amount of memory and make the scale of the circuit smaller.

The crosstalk canceling signal generating filter as the FIR filter having two taps similar to the third example is disposed between the direction localizing filter and the band compositing circuit in the structure shown in Fig. 9, while being disposed at the rear of the band compositing circuit, i.e., on the output side, in the structure shown in Fig. 10. However, the crosstalk canceling signal generating filter may be disposed in front of the subsampling circuit, i.e., on the input side, or between the subsampling circuit and the direction localizing filter, and may receive only the low-frequency component output from the subsampling circuit as the target of processing, resulting in the similar effect.

As described above, the sound image localization apparatus in accordance with the second embodiment includes the comb filters in which the coefficients of the multipliers 510x1 to 510x10 shown in Fig. 5 are the same, whereby the operation using the filters requires only one parameter, i.e., the coefficient, and therefore, the amount of memory for holding the coefficient is reduced while making possible a high level of sound image localization.

Although in the second embodiment the outline of the structure is the same as the feedback type sound image localization apparatus shown in Fig. 18, the feedforward type sound image localization apparatus shown in Fig. 17(b) may be used, or a comb filter can be used for the sound image localization apparatus of the first embodiment shown in Fig. 1(b), resulting in the same effect.

[Embodiment 3]

A sound image localization apparatus in accordance with a third embodiment of this invention employs a circuit including delay buffers and accumulation registers (or memories) instead of comb filters of the second embodiment.

Fig. 11 is a block diagram showing a structure of the sound image localization apparatus of the third embodiment. The outline of the structure of the sound image localization apparatus of the third embodiment includes the same feedback structure as the prior art shown in Fig. 18, similar to the second embodiment. As shown in Fig. 11, the sound image localization apparatus comprises adders 1103a, 1103b, 1103c, and 1103d, main-path filters 1107a and 1107b, crosstalk-path filters 1108a and 1108b, delaying units 1111a to 1111j, and multipliers 1110f1 to 1110f4, 1110x1, 1110x5, 1110x6, and 1110x10. Input sound signals are input through input terminals 1104a and 1104b, and subjected to signal processing, and the resulting signals are output through output terminals 1105a and 1105b. As in Fig. 2,

dashed lines in the rows of the delaying units represent an arbitrary number of the delaying units.

In the figure, the portion including the adder 1103c, the multipliers 1110f1 and 1110f2, and the delaying unit 1111m, and the portion including the adder 1103d, the multipliers 1110f3 and 1110f4, and the delaying unit 1111n constitute low-pass filters similar to that in the second example of the second embodiment. In place of the comb filters constituting the crosstalk canceling signal generating filters (1806a and 1806b in Fig. 18), the delaying units 1111a, 1111b, 1111c to 1111f, and 1111g to 1111j, the multipliers 1110x1, 1110x5, 1110x6, and 1110x10, and the adders 1103e to 1103h are included in the sound image localization apparatus of the third embodiment.

The comb filter included in the apparatus of the second embodiment shown in Fig. 5 performs the operation equivalent to calculating the average of data held in the delaying units 511c to 511f at a time so as to generate a crosstalk canceling signal at the time. Accordingly, based on the crosstalk canceling signal obtained at a certain time, the oldest among the data is reduced to one n-th, and one n-th of the newest data is added to the data. Thereby, a crosstalk canceling signal at a next time is obtained.

In the sound image localization apparatus shown in Fig. 11, the delaying units 1111a and 1111b hold immediately previous signals. Among data held by the delaying units 1111c to 1111f and 1111g to 1111j, the oldest data, i.e., the data held in the delaying units 1111f and 1111j having maximum delay in Fig. 11, are multiplied by one n-th in the multipliers 1110x5 and 1110x10, and the results are subtracted from the immediately previous signals by the adders 1103g and 1103h, respectively. Among the data held by the delaying units, the newest data, i.e., the data held in the delaying units 1111c and 1111g having minimum delay in Fig. 11, are multiplied by one n-th in the multipliers 1110x1 and 1110x6, and the results are added to the results of the subtraction by the adders 1103e and 1103f. The results of the addition are crosstalk canceling signals similar to that is obtained from the operation of the comb filter. The generated signals are held by the delaying units 1111a and 1111b to generate signals at a next time.

In the sound image localization apparatus of the third embodiment, the data held in the delaying units 1111c to 1111f and 1111g to 1111j are accessed only when the oldest data are taken and when the newest data are written. Since the delaying unit included in the comb filter of the second embodiment is frequently accessed, a high-speed memory is required. In contrast, a relatively low-speed memory can be employed for the delaying unit included in the third embodiment. The amounts of multiplication and addition are further reduced in the third embodiment than in the second embodiment. Thus, the sound image localization apparatus in accordance with the third embodiment solves the access time problem of a memory, i.e., (C) of the first problem, and the processing speed problem, i.e., the second problem.

As explained above, the sound image localization apparatus of the third embodiment includes delay buffers (the delaying units 1111c to 1111f and 1111g to 1111j in Fig. 11) and accumulation registers (the delaying units 1111a and 1111b in Fig. 11) as filters for crosstalk cancellation in place of the comb filter. Thereby, the incidence of access to a memory, and the loads of addition and multiplication are reduced. As a result, in a computer system implementing the sound image localization apparatus, even when the amount of a high-speed memory and the processing speed of a processor are limited, a high level of sound image localization is possible.

Similar to the first embodiment, the outline of the structure in the third embodiment is the same feedback type sound image localization apparatus as shown in Fig. 18. However, the feedforward type apparatus shown in Fig. 17 (b) is possible, and a circuit substituting the comb filter can be employed in the apparatus of the first embodiment shown in Fig. 1(b).

[Embodiment 4]

A sound image localization apparatus in accordance with a fourth embodiment of this invention can localize a sound image by switching the apparatus to feedforward or feedback.

Fig. 12 is a diagram showing a structure of a first example of the sound image localization apparatus of the fourth embodiment. As shown in the figure, the sound image localization apparatus comprises the apparatus shown in Fig. 18 and, further, adders 1203c and 1203d, and switches 1218a and 1218b.

Fig. 12 shows a case where the switches 1218a and 1218b both turn to feedback (an FB side in the figure). In this situation, crosstalk canceling signals generated by crosstalk canceling signal generating filters 1206a and 1206b are input to the adders 1203a and 1203b. That is, the crosstalk canceling signal is output to the input side, so the apparatus is a feedback type, and is equivalent to the apparatus shown in Fig. 18. In this case, the apparatus of the fourth embodiment operates in a similar way to the apparatus of the second example in the BACKGROUND IN THE INVENTION section.

As opposed to this, when the switches 1218a and 1218b both turn to feedforward (an FF side in the figure), crosstalk canceling signals generated by crosstalk canceling signal generating filters 1206a and 1206b are input to the adders 1203c and 1203d. That is, the crosstalk canceling signal is output to the output side, so the apparatus is a feedforward type, and equivalent to the apparatus shown in Fig. 17(b). In this case, the apparatus of the fourth embodiment operates in a similar way to the apparatus of the second example in the BACKGROUND IN THE INVENTION section.

In general, the feedback type apparatus has good reproducibility of the low-frequency component. However, as described about the third problem in the prior art, when a loudspeaker included in an acoustic system using the sound image localization apparatus is small in diameter, the large energy of the low-frequency component causes sound distortion. The feedforward type apparatus has high-pass frequency characteristics which cut off the low-frequency component, and is suited to that system. Accordingly, the sound image localization apparatus of the fourth embodiment switches a feedback or feedforward type apparatus by the switches, so that when a loudspeaker with a large diameter is used, the apparatus operates as a feedback circuit so that good sound quality can be reproduced, while when a loudspeaker with a small diameter is used, the apparatus operates as a feedforward circuit so as to prevent sound distortion.

Thus, the sound image localization apparatus of the fourth embodiment includes the switches 1218a and 1218b, thereby becoming suited to an acoustic system, to which the apparatus is applied, by switching feedback and feedforward.

Fig. 13 is a diagram showing a structure of a second example of the sound image localization apparatus of the fourth embodiment. Fig. 14 is a diagram showing a structure of a third example of the sound image localization apparatus of the fourth embodiment. As shown in Fig. 13, the second example of the apparatus is the apparatus according to the first embodiment that crosstalk cancellation is performed on the input side, and further that switches are added. The third example of the apparatus shown in Fig. 14 comprises the feedback type apparatus in Fig. 18 and, further, switches, as the first example does. While in the first example the switches are disposed at the rear of the crosstalk canceling signal generating filter, i.e., on the output side, in the third example the switches are disposed in front of the filter, i.e., on the input side. The second and third examples of the sound image localization apparatus shown in Figs. 13 and 14 can be suited to an acoustic system by switching feedback and feedforward.

[Embodiment 5]

A sound image localization apparatus in accordance with a fifth embodiment has capability of changing an initial delay in generating a crosstalk canceling signal.

Fig. 15 is a diagram showing a structure of the sound image localization of the fifth embodiment. As shown in the figure, the sound image localization of the fifth embodiment is such that delaying units 1511a to 1511d and switches 1518a and 1518b are added to the feedback type apparatus shown in Fig. 18.

In the situation shown in Fig. 15, the switches 1518a and 1518b are set in a way that the crosstalk canceling signal generating filters 1506a and 1506b output generated signals to the adders 1503b and 1503a without passing the signals through the delay units. In this situation, the sound image localization of the fifth embodiment is equivalent to the apparatus shown in Fig. 18. The sound image localization apparatus of the fifth embodiment with this setting operates in a similar way to the second example in the prior art.

The sound image localization apparatus can use delayed crosstalk canceling signals held in the delaying units 1511b and 1511d, or delayed crosstalk canceling signals held in the delaying units 1511a and 1511c, depending on the setting of the switches 1518a and 1518b, respectively. The sound image localization apparatus of the fifth embodiment with this setting operates in a similar way to that described in the first embodiment, except that the delayed crosstalk canceling signal is used for crosstalk cancellation.

In calculation by the crosstalk canceling signal generating filter, the input signal is multiplied by the coefficient shown in the equation 7-3, representing the ratio of the head related transfer functions SC and SM shown in Fig. 19(b). As is apparent from Fig. 19(b), as the crosstalk path is longer than the main path; there occurs a difference in the times of arrivals of sound signals from two loudspeakers. When the angle of the two loudspeakers is small, the difference in the arrival time is small. When the angle is large, the difference in the arrival time is large. This must be taken into account for sound image localization. In the crosstalk canceling signal generating filter, the arrival time difference is equivalent to the amount of an initial delay. Therefore, in an acoustic system using a sound image localization apparatus, when the fixed amount of an initial delay is used, if the positions of setting up the loudspeakers are changed, crosstalk cancellation is not possibly satisfactory.

In the crosstalk canceling signal generating filter, in cases except for initial delay, the frequency characteristics do not change to a large extent if the angle of two loudspeakers is around 30 to 60 degrees. The change in the angle can be coped with by switching initial delays. The sound image localization apparatus of the fifth embodiment can change the amount of an initial delay in a step-by-step manner by setting of the switches.

As described above, the sound image localization apparatus in accordance with the fifth embodiment further includes the delaying units 1511a to 1511d and the switches 1518a and 1518b, thereby performing a high level of sound image localization by coping with a case where the angle of two loudspeakers are changed in an acoustic system to which the apparatus is applied.

[Embodiment 6]

A sound image localization apparatus in accordance with a sixth embodiment changes a crosstalk canceling signal generating filter.

Fig. 16 is a block diagram showing a structure of the sound image localization apparatus of the sixth embodiment. As shown in the figure, the sound image localization apparatus comprises main-path filters 1607a and 1607b, crosstalk-path filters 1608a and 1608b, adders 1603a to 1603f, crosstalk canceling signal generating filters 1606a and 1606b, delaying units 1611a to 1611d, multipliers 1610x1 to 1610x4, inverting circuits 1631a and 1631b, and switches 1618a to 1618f. The apparatus receives input sound signals through input terminals 1604a to 1604d, and outputs processed signals through output terminals 1605a and 1605b.

The delaying units 1611a and 1611b, the multipliers 1610x1 and 1610x2, and the adder 1603c constitute a first FIR filter having two taps. The delaying units 1611c and 1611d, the multipliers 1610x3 and 1610x4, and the adder 1603d constitute a second FIR filter having two taps. Either filter functions as a crosstalk canceling signal generating filter. The switches 1618a to 1618f are switched depending on the distance between two loudspeakers of an acoustic system using the sound image localization apparatus.

The main-path filters 1607a and 1607b, the crosstalk-path filters 1608a and 1608b, the adders 1603a to 1603d, and the crosstalk canceling signal generating filters 1606a and 1606b are similar to those of the feedback type sound image localization apparatus shown in Figs. 1(a) and 1(b).

The operation of the sound image localization apparatus of the sixth embodiment will be described as to when the distance between two loudspeakers is wide or narrow.

At first, when the distance between two loudspeakers is wide, the switches 1618a, 1618b, 1618e, and 1618f are set to respective W sides, while the switches 1618c and 1618d are set to be released. This is the situation shown in the figure. In this case, sound signals input through the input terminals 1604c and 1604d are output to the output terminals 1605a and 1606b, passing through the sound image localization apparatus of the sixth embodiment.

Signals input through the input terminals 1604a and 1604b are subjected to directional localization, and then, input through the switches 1618a and 1618b to the crosstalk canceling signal generating filters 1606a and 1606b. Thereafter, signals output from the first and second FIR filters each having two taps are not used because the switches 1618c and 1618d are released. Therefore, the operation of the apparatus is equivalent to that of the feedback type sound image localization apparatus shown in Fig. 18.

As opposed to this, when the distance between the two loudspeakers is narrow, the switches 1618a, 1618b, 1618e, and 1618f are set to N sides, while the switches 1618c and 1618d are closed. Thus, signals after subjected to directional localization are processed by the first and second FIR filters each having two taps, and then, input through the switches 1618c and 1618d to the adders 1603a and 1603b. That is, the first and second FIR filters are used for crosstalk cancellation.

On the other hand, the phases of sound signals input through the input terminals 1604c and 1604d are inverted by the inverting circuits 1631a and 1631b, and then, input through the switches 1618a and 1618b to the filters 1606a and 1606b. The filters 1606a and 1606b generate signals based on the phase inverted signals, and output the generated signals to the adders 1603a and 1603b.

In this case, the channels to the adders 1603a and 1603b function as main paths due to the switches 1618e and 1618f, while the filters 1606a and 1606b generate crosstalk canceling signals. This is effective processing when a sound image to be localized at the front position and a sound image to be localized at an arbitrary position (at the side or the rear) coexist in a sound signal. When the distance between two loudspeakers is narrow, if a sound image to be localized at the front is extended further outward, stereophony increases.

That is, in the apparatus of the sixth embodiment, a sound signal of the sound image to be localized at the arbitrary position is input through the input terminals 1604a and 1604b, while a sound signal of the sound image to be localized at the front position is input through the input terminals 1604c and 1604d. When the distance between two loudspeakers is wide, the sound image to be localized at the front position is output as it is, while the sound image to be localized at the arbitrary position is subjected to crosstalk cancellation similar to that in the first embodiment. When the distance between the two loudspeakers is narrow, a crosstalk canceling signal is generated for the sound image to be localized at the front position to extend the sound image outward. On the other hand, for the sound image to be localized at the arbitrary position, the crosstalk canceling signal generating filter used for sound localization multiplies an input signal by the coefficient shown in the equation 7-3, representing the ratio of the head related transfer functions SC and SM shown in Fig. 19(b). Because the distance between the two loudspeakers is narrow, the ratio is small, so that it is possible to use a filter having a small number of taps. Therefore, the filter having two taps is used.

As described above, the sound image localization apparatus of the sixth embodiment comprises the conventional feedback type sound image localization apparatus and, further, the FIR filters with two taps comprising the delaying units 1611a to 1611d, the multipliers 1610x1 to 1610x4, and the adders 1603c to 1603d, the switches 1618a to 1618d, and the inverting circuits 1631a and 1631b, whereby when the distance between two loudspeakers is wide, the feed-

back sound localization similar to that in the first embodiment is performed, while when the distance between two loudspeakers is narrow, the outward extension of a sound image to be localized at the front is performed as well as the feedback sound localization.

Note that although the apparatus of the sixth embodiment is based on the feedback type sound image localization apparatus shown in Fig. 18, the apparatus of the sixth embodiment can be based on the feedforward type apparatus shown in Fig. 17(b) or the apparatus of the first embodiment shown in Fig. 1(b).

Claims

1. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for generating a crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
   direction localizing means for localizing the direction of a virtual sound source position by processing the signal subjected to crosstalk cancellation in said crosstalk canceling means.

2. The sound image localization apparatus of claim 1 wherein

   said crosstalk canceling means comprise first and second crosstalk canceling signal generating filters, and first and second adders, said first adder adding a first sound signal and a signal generated by said second crosstalk canceling signal generating filter, and said second adder adding a second sound signal and a signal generated by said first crosstalk canceling signal generating filter;
   said direction localizing means comprise first and second main-path filters, first and second crosstalk-path filters, and first and second adders, said first adder adding a signal processed by said first main-path filter and a signal processed by said second crosstalk-path filter, and said second adder adding a signal processed by said second main-path filter and a signal processed by said first crosstalk-path filter.

3. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for including a comb filter to generate the crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
   direction localizing means for localizing the direction of a virtual sound source position.

4. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for generating a crosstalk canceling signal generated at a certain time, holding the crosstalk canceling signal, delaying the crosstalk canceling signal held, holding the plurality of crosstalk canceling signals delayed, and multiplying some of the plurality of crosstalk canceling signals held, by a predetermined coefficient to generate the crosstalk canceling signal at a time following the certain time; and
   direction localizing means for localizing the direction of a virtual sound source position.

5. The sound image localization apparatus of any of claim 3 and claim 4 wherein

   said apparatus further comprises a low-pass filter processing a signal input to or output from said crosstalk canceling means.

6. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a switch switching the crosstalk canceling signal generated by said crosstalk canceling signal generating filter to the output side f said crosstalk canceling signal generating filter or to the input side of said crosstalk canceling signal generating filter; and
   direction localizing means for localizing the direction of a virtual sound source position.

7. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a delaying unit delaying a signal input to or output from said crosstalk canceling signal generating filter by various times; and
   direction localizing means for localizing the direction of a virtual sound source position.

8. A sound image localization apparatus receiving an input sound signal to be localized in a first direction, and an input sound signal to be localized in a second direction, performing signal processing to the input sound signals, localizing virtual sound images, and outputting sound image localization signals, said apparatus comprising:

   crosstalk canceling means comprising a first filter, a second filter, and a switch switching first and second modes; in the first mode said first filter functioning as a filter generating the crosstalk canceling signal, and in the second mode said second filter functioning as a filter generating the crosstalk canceling signal while said first filter functioning as a filter localizing the second direction; and
   direction localizing means for localizing the direction of a virtual sound source position.

Fig.1 (a)

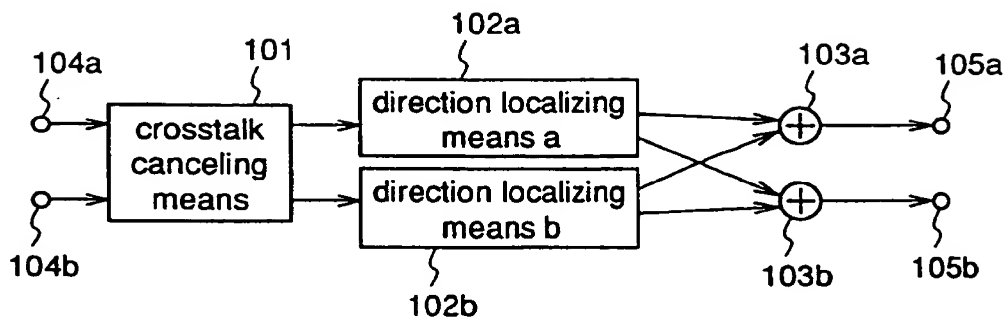
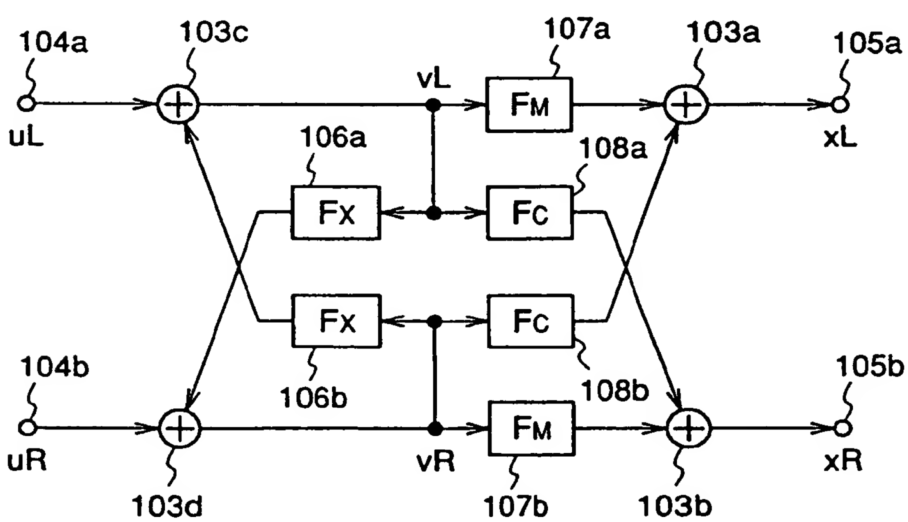

104a
101
102a
103a
105a
crosstalk canceling means
direction localizing means a
direction localizing means b
104b
102b
103b
105b

Fig.1 (b)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uL
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xL
108a
Fx
Fc
Fx
Fc
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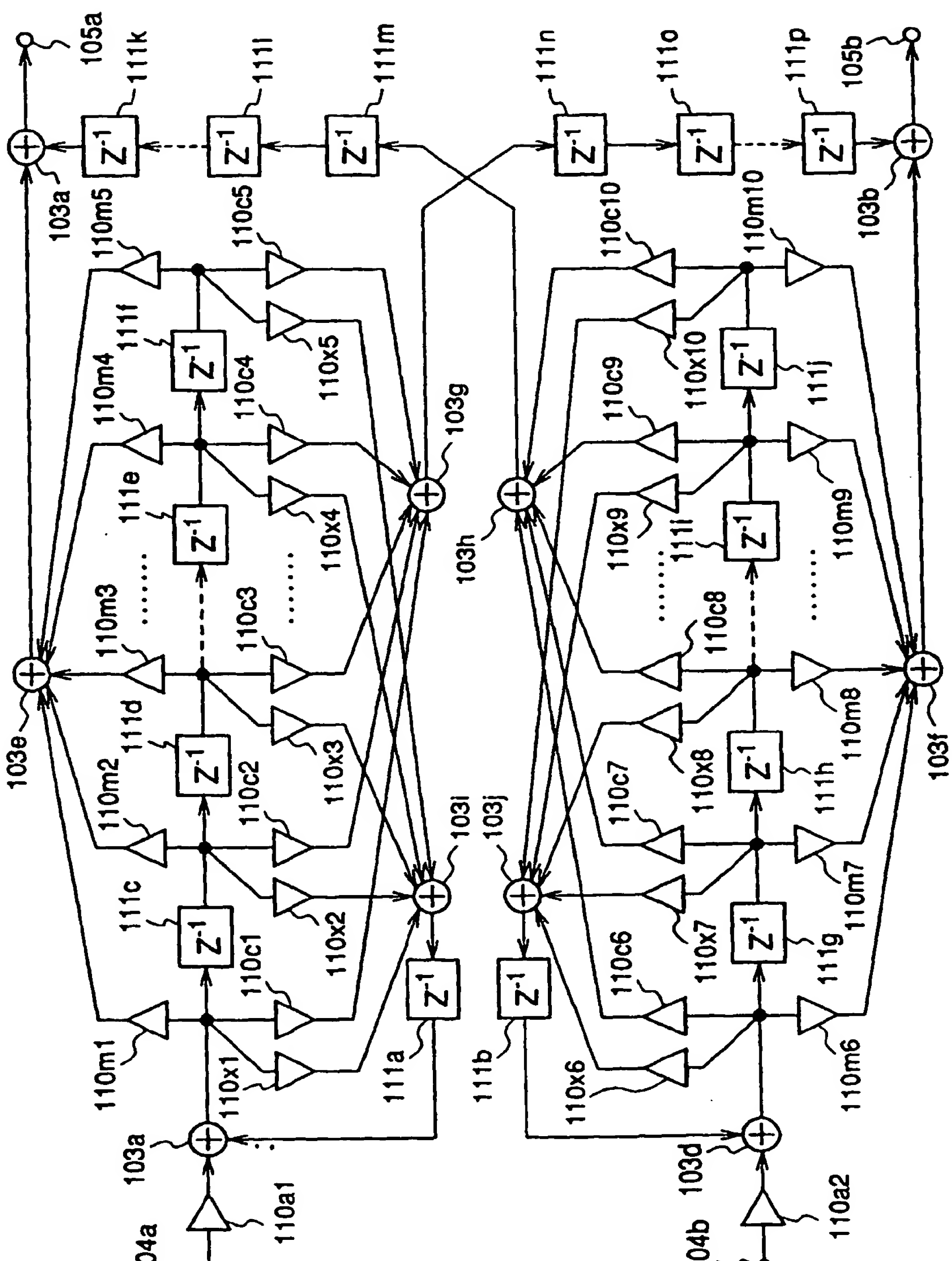
FM
uR
vR
xR
103d
107b
103b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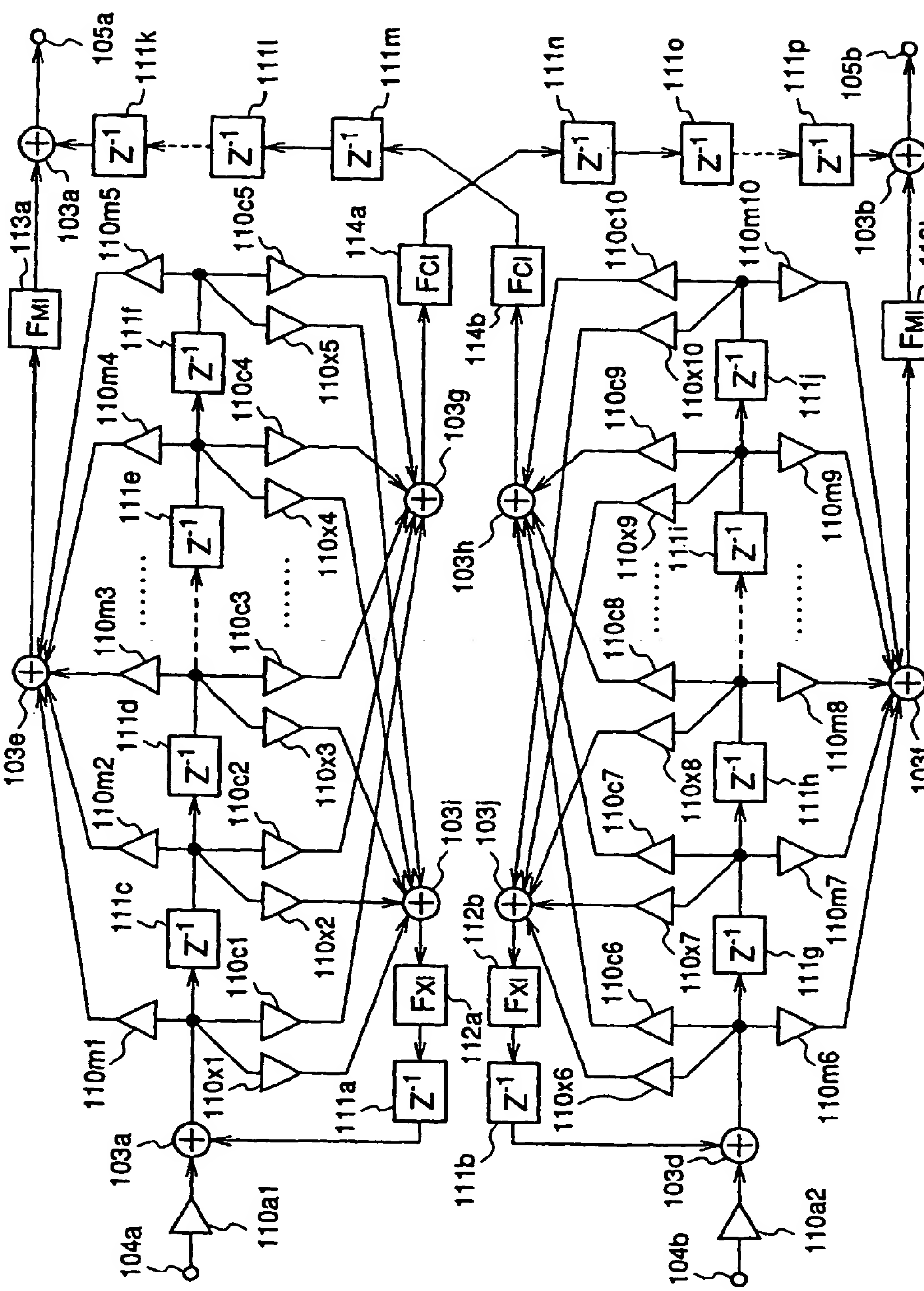
110a1
103a
110m1
110x1
110c1
111a
111c
110m2
110c2
110x2
103i
111d
110x3
103e
110m3
110c3
111e
110x4
110m4
110c4
103g
111f
110x5
110m5
110c5
103a
111k
111l
111m
105a
104b
110a2
103d
111b
110x6
110c6
110m6
111g
110x7
110m7
103j
110c7
111h
110x8
110m8
103f
110c8
111i
110x9
110m9
103h
110c9
111j
110x10
110c10
110m10
103b
111n
111o
111p
105b

Fig.2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103a
110m1
110x1
110c1
111a
111c
110m2
110c2
110x2
111d
103e
110m3
110c3
110x3
111e
110m4
110c4
110x4
111f
110m5
110c5
110x5
113a
FMI
103a
Z-1
111k
105a
111l
111m
114a
FCI
114b
103g
103i
112a
FXI
111n
111o
111p
105b
103b
113b
104b
110a2
103d
111b
112b
110x6
110c6
110m6
111g
110x7
110c7
110m7
103j
111h
110x8
110m8
103f
110c8
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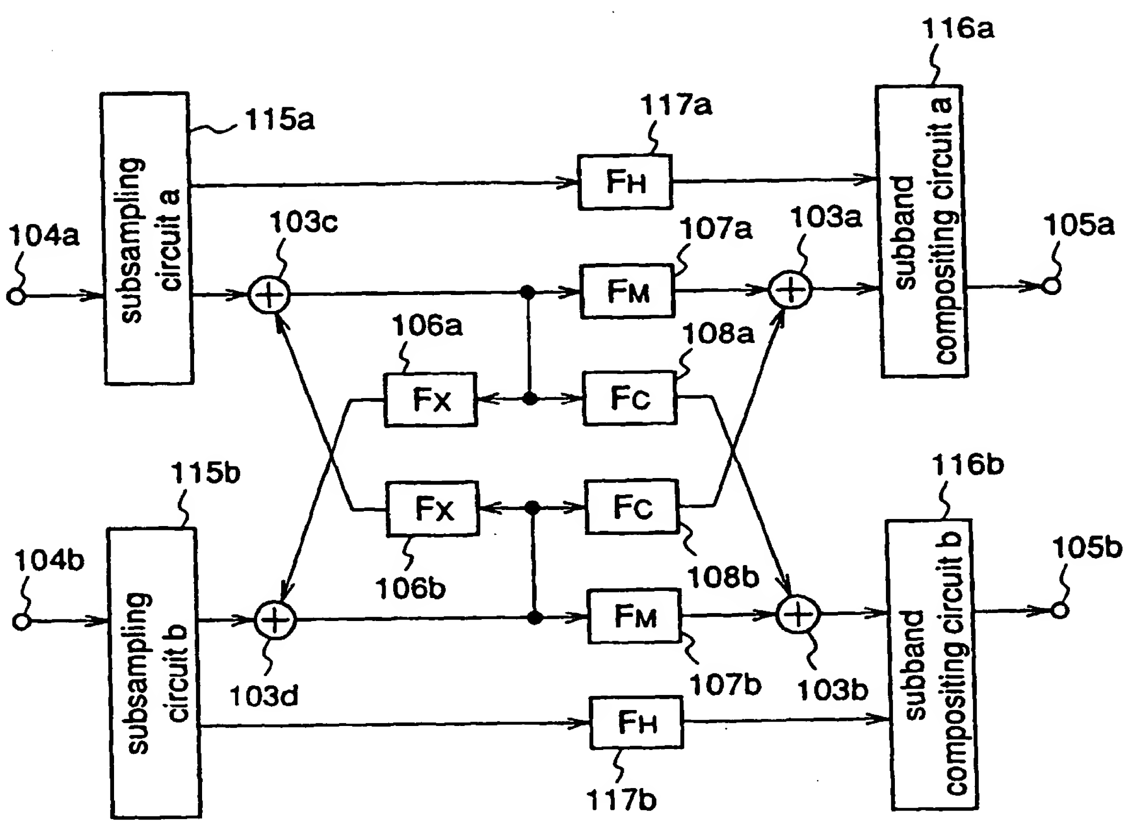
110m9
110c9
111j
110x10
110c10
110m10

Fig.3

Fig.4



115a
116a
117a
subsampling circuit a
FH
subband compositing circuit a
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103c
107a
103a
105a
FM
106a
108a
FX
FC
115b
116b
FX
FC
104b
106b
108b
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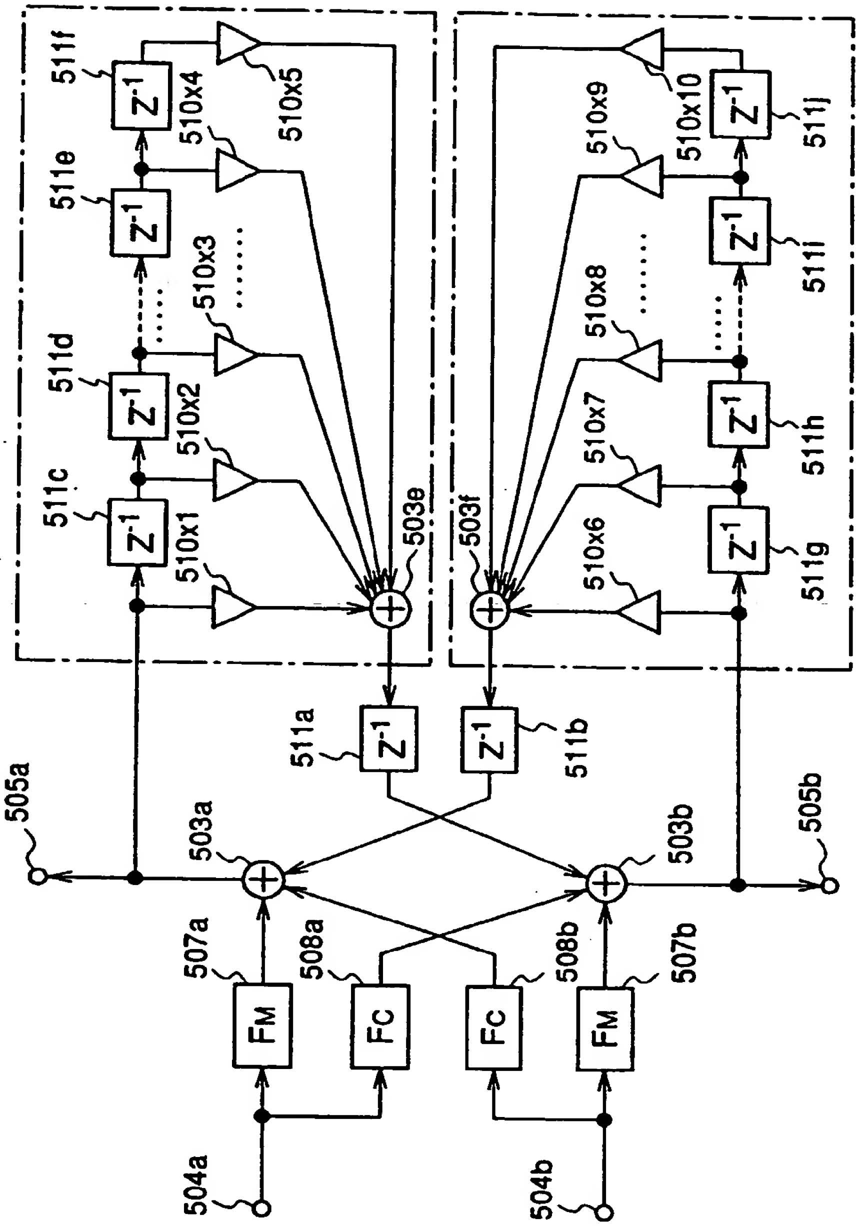
subsampling circuit b
FM
103d
107b
103b
subband compositing circuit b
FH
117b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503f
511c
511d
511e
511f
510x1
510x2
510x3
510x4
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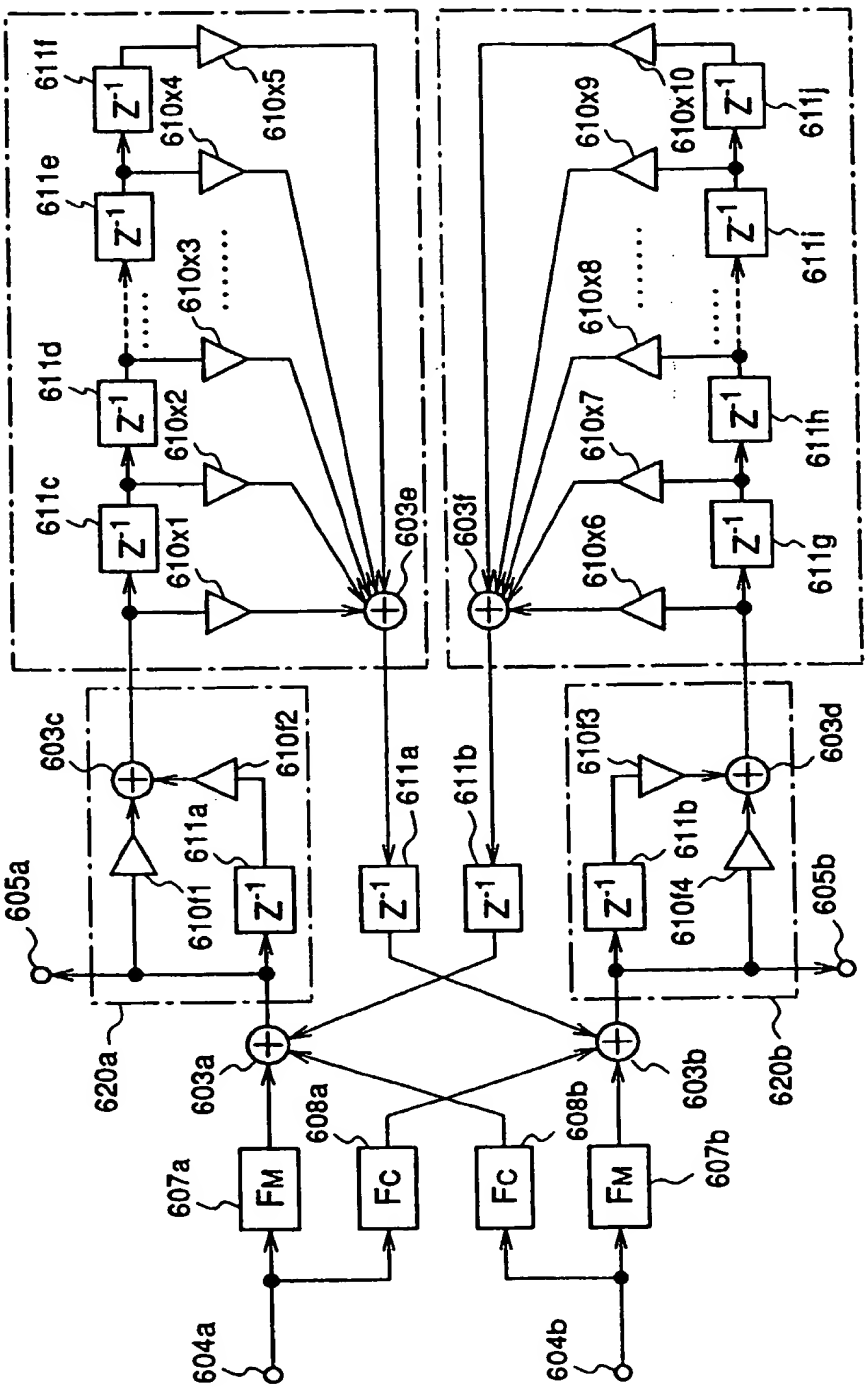
510x7
510x8
510x9
510x10
511g
511h
511i
511j
Z^{-1}

Fig.5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604b
607a
607b
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Fc
Fc
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608b
603a
603b
620a
620b
605a
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610f1
610f2
610f3
610f4
611a
611b
603c
603d
Z^{-1}
611a
611b
603e
603f
611c
611d
611e
611f
611g
611h
611i
611j
610x1
610x2
610x3
610x4
610x5
610x6
610x7
610x8
610x9
610x10

Fig.6

Fig.7 (a)

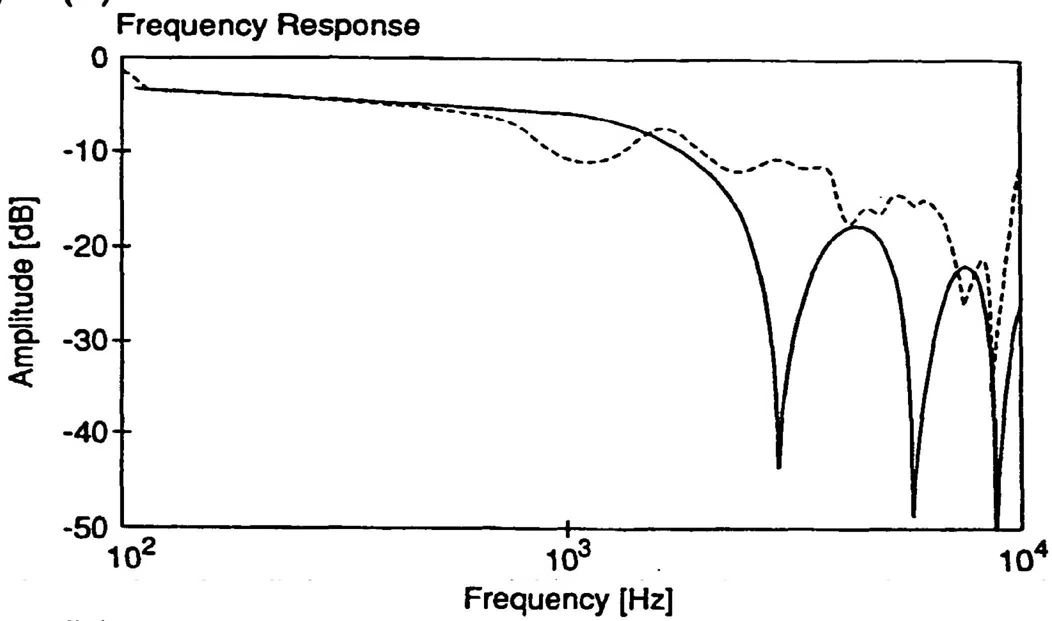
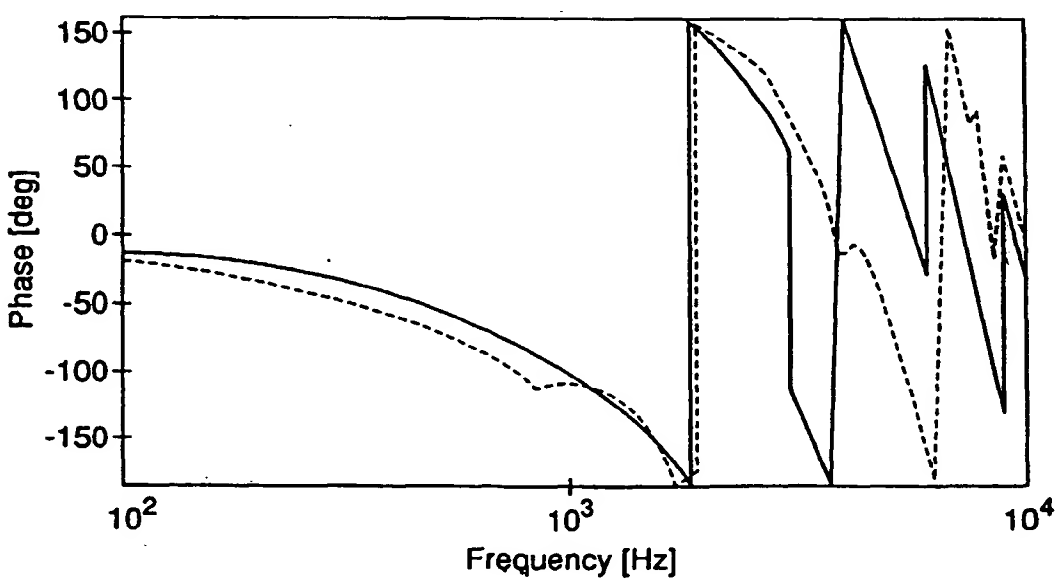


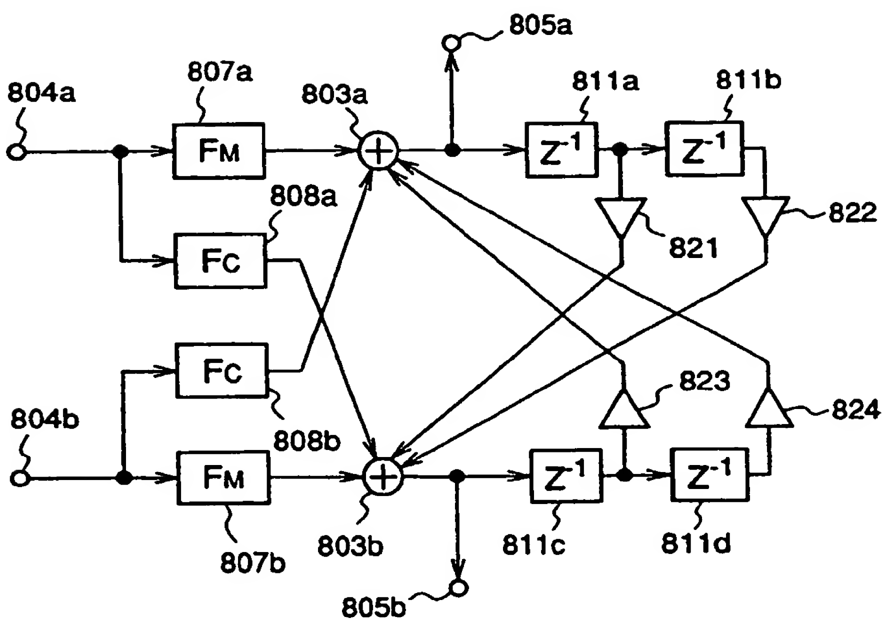
Fig.7 (b)



-------- Measurement Value

——— Comb. Filter

Fig.8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807a
803a
811a
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Z-1
Z-1
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822
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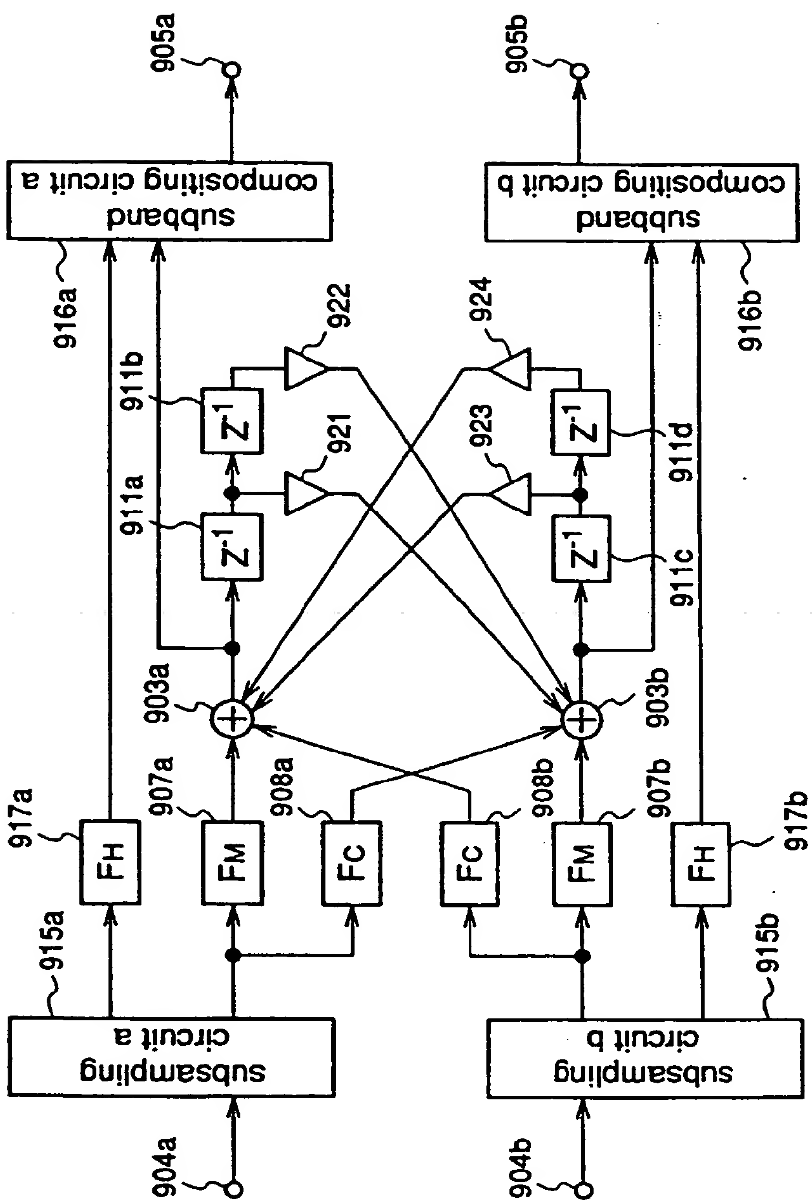
811c
811d
805b



subsampling circuit a
subsampling circuit b
subband compositing circuit a
subband compositing circuit b
FH
FM
Fc
Z-1
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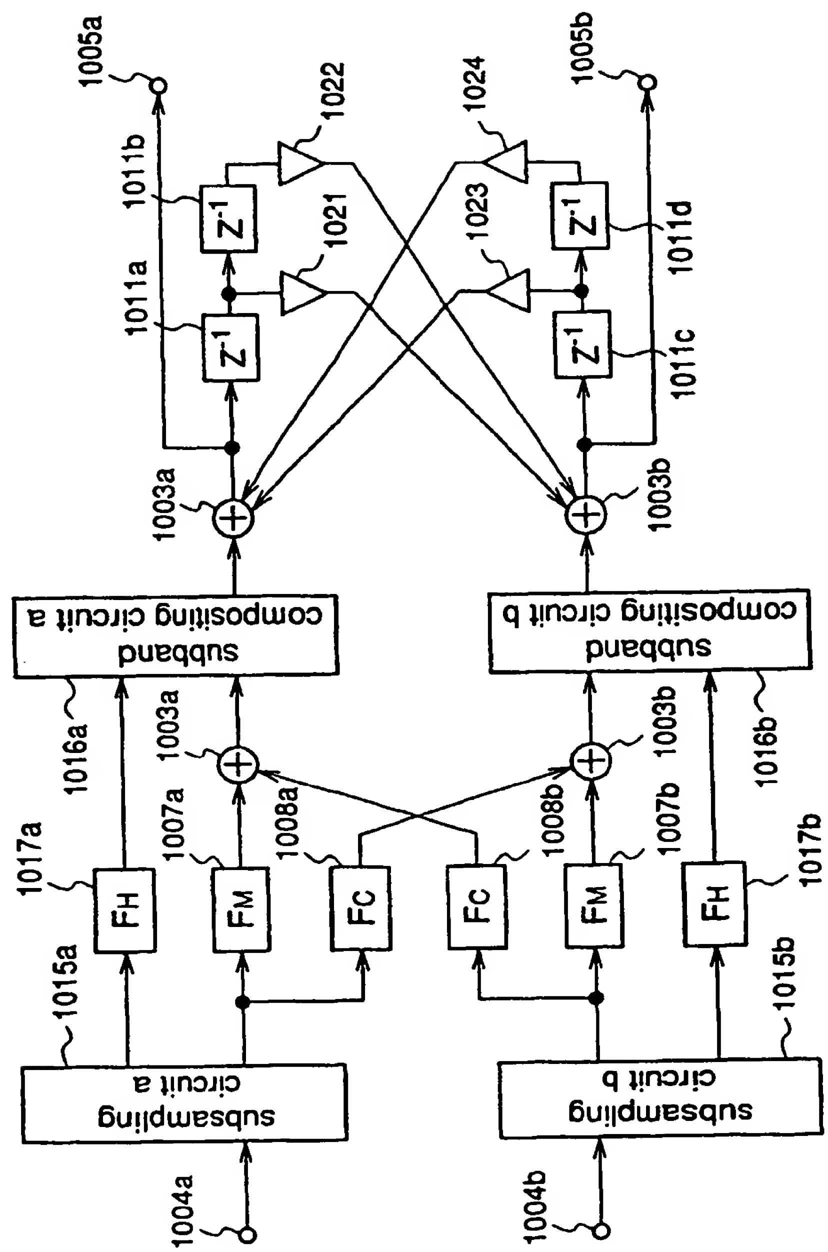
904b
905a
905b
903a
903b
907a
907b
908a
908b
911a
911b
911c
911d
915a
915b
916a
916b
917a
917b
921
922
923
924

Fig.9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subsampling circuit b
subband compositing circuit a
subband compositing circuit b
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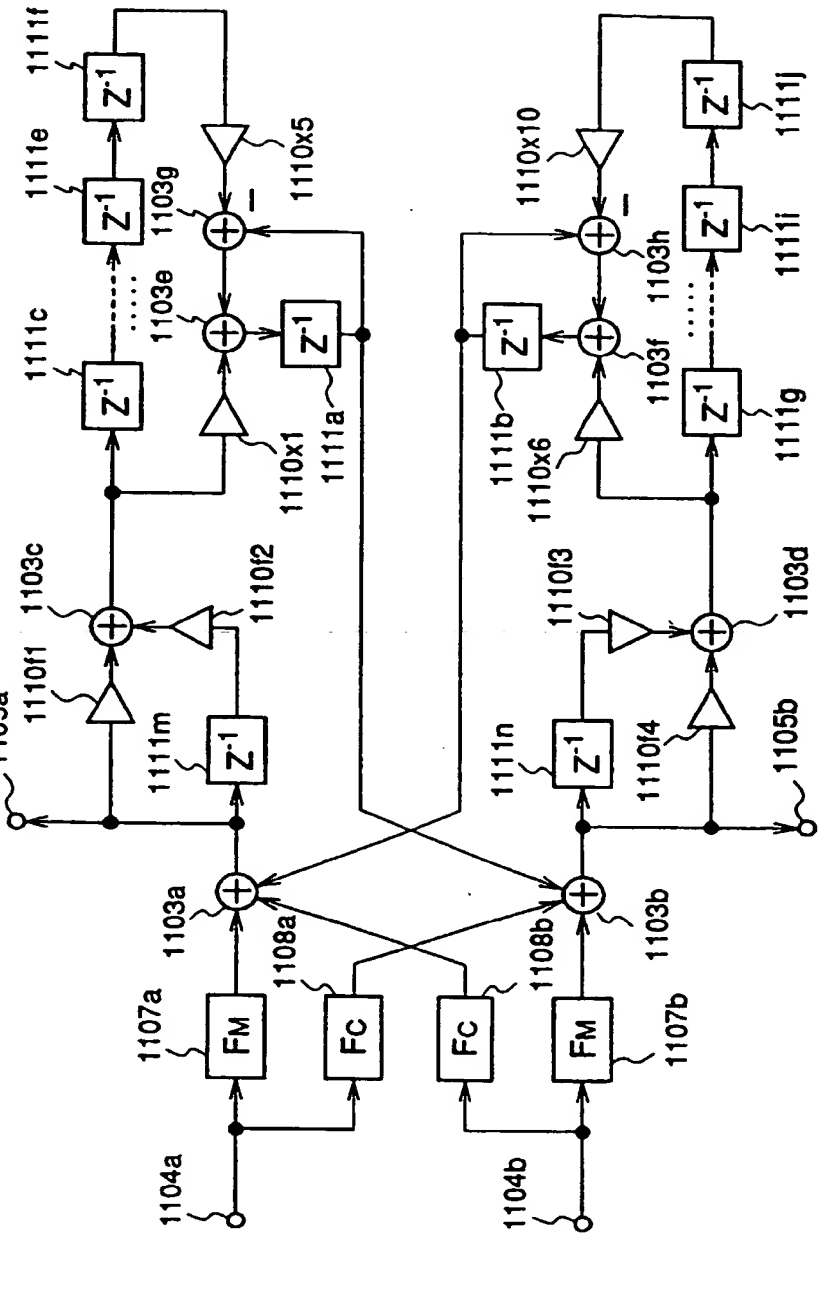
FM
FC
FC
FM
FH
Z-1
Z-1
Z-1
Z-1
1004a
1004b
1015a
1015b
1017a
1017b
1007a
1007b
1008a
1008b
1003a
1003b
1016a
1016b
1003a
1003b
1011a
1011b
1011c
1011d
1021
1022
1023
1024
1005a
1005b

Fig.10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FM
Fc
Fc
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1108b
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1103b
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1111m
1111n
Z-1
1110f1
1110f2
1110f3
1110f4
1103c
1103d
1110x1
1110x6
1111a
1111b
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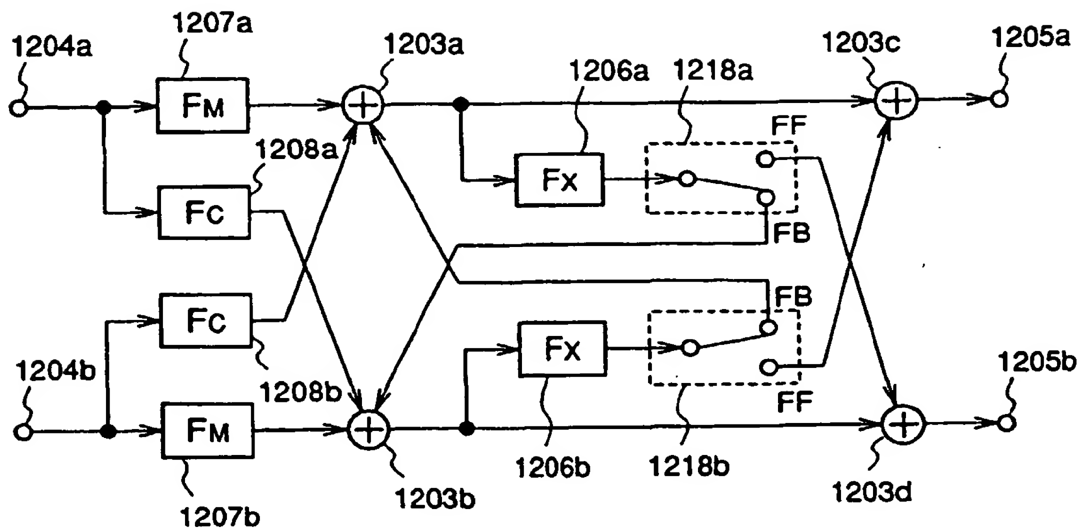
1111e
1111f
1111g
1111i
1111j

Fig.11

Fig.12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1203a
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1218a
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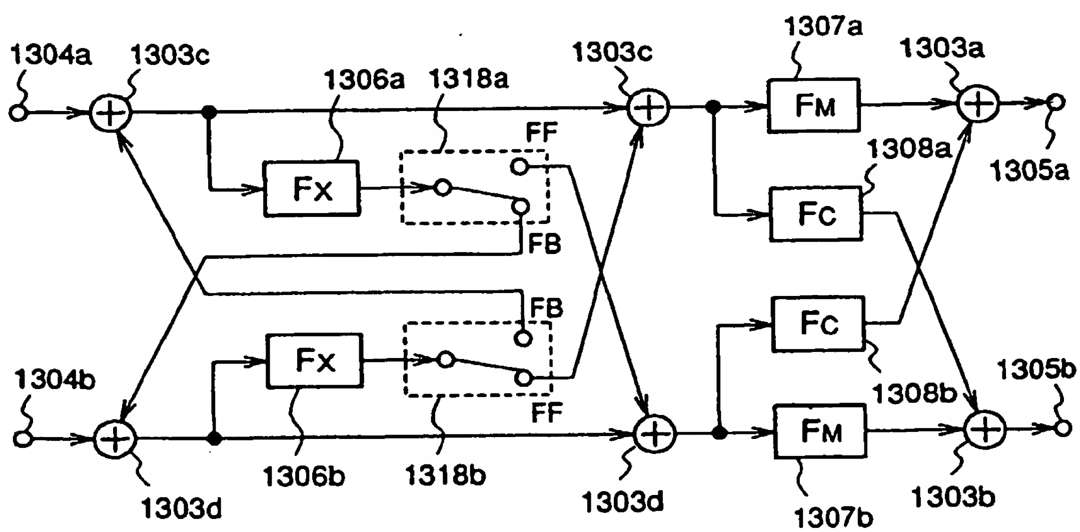
1205a
FF
1208a
Fc
Fx
FB
FB
Fc
Fx
1204b
1208b
FF
1205b
FM
1206b
1218b
1203d
1203b
1207b

Fig.13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FF
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Fc
FB
Fc
Fx
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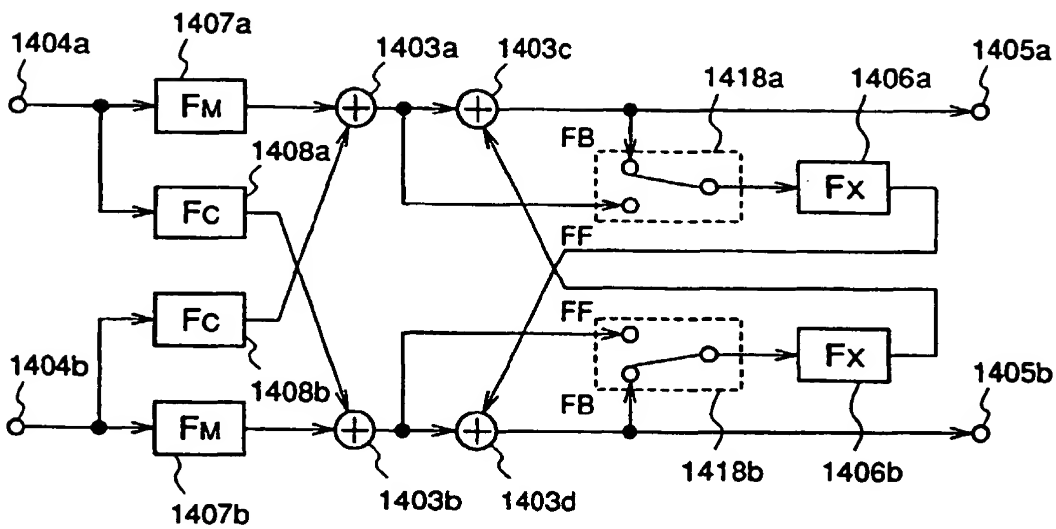
1305b
FF
FM
1306b
1318b
1303d
1303d
1307b
1303b

Fig.14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FB
Fx
Fc
FF
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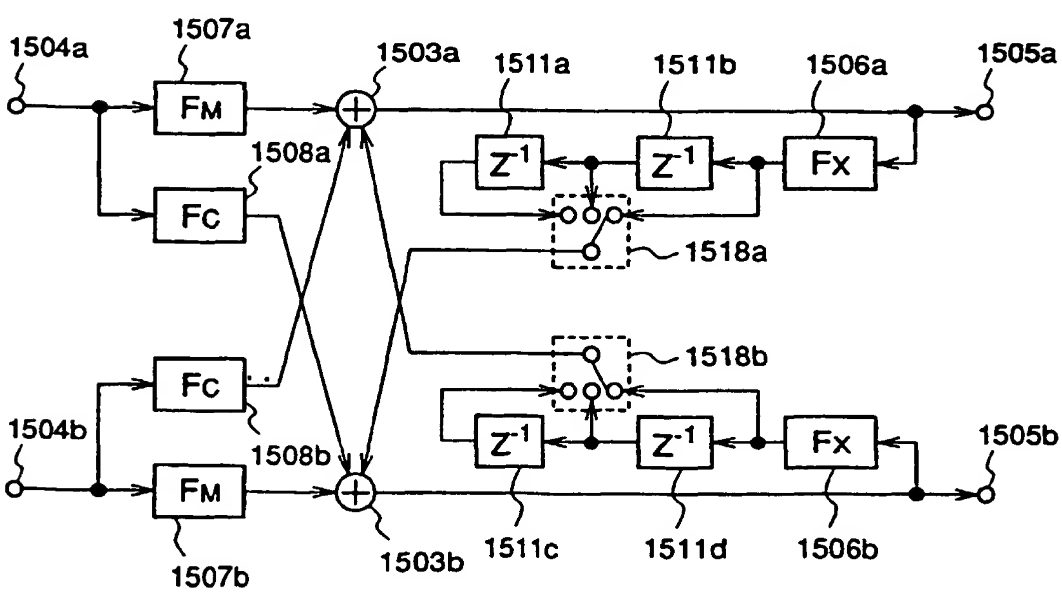
FM
1418b
1406b
1407b
1403b
1403d

Fig.15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1503a
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1511b
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FM
1508a
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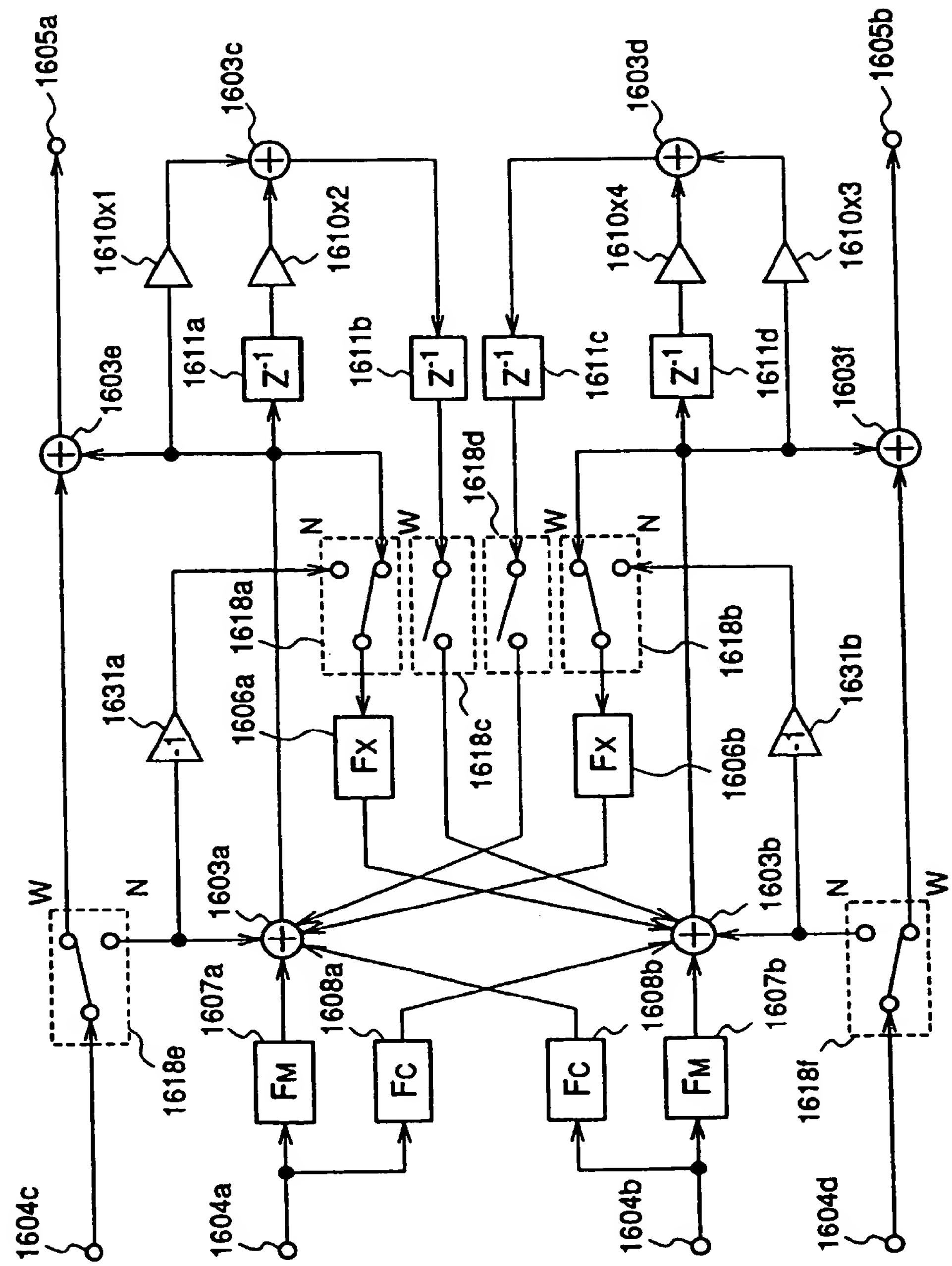
Z-1
Fx
Fc
1518a
1518b
Fc
1504b
1508b
Z-1
Z-1
Fx
1505b
FM
1507b
1503b
1511c
1511d
1506b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1603d
1605b
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1610x4
1610x3
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1611b
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1611d
1603f
Z^{-1}
Z^{-1}
Z^{-1}
Z^{-1}
1618d
N
W
W
N
1618a
1618b
1631a
1631b
-1
-1
1606a
1618c
1606b
Fx
Fx
W
N
1603a
1603b
N
W
1607a
1608a
1608b
1607b
FM
Fc
Fc
FM
1618e
1618f
1604c
1604a
1604b
1604d

Fig.16

Prior Art

Fig.17 (a)

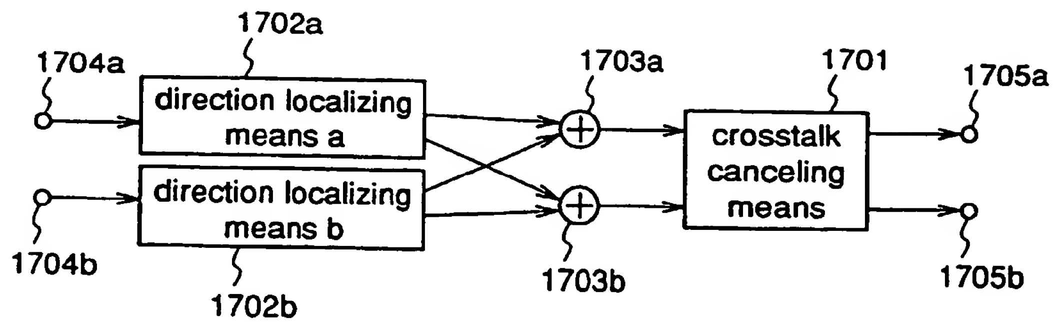


Fig.17 (b)

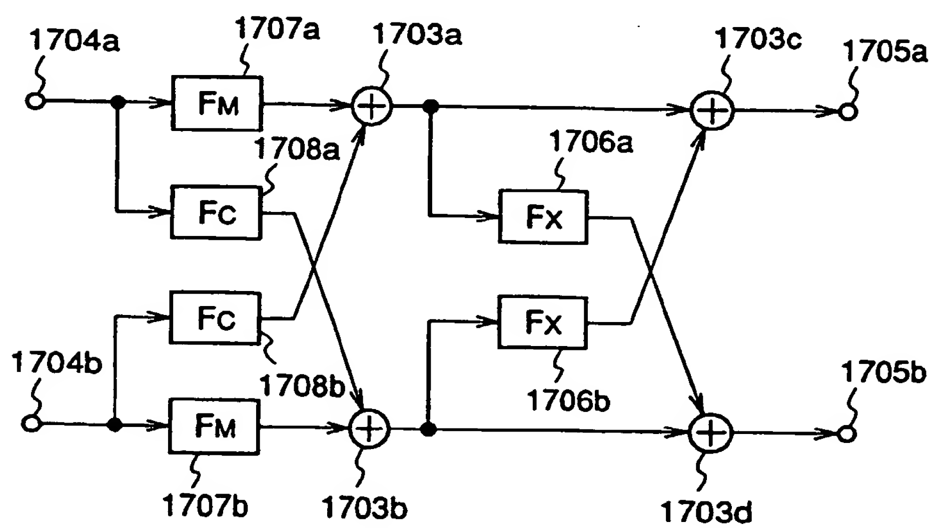
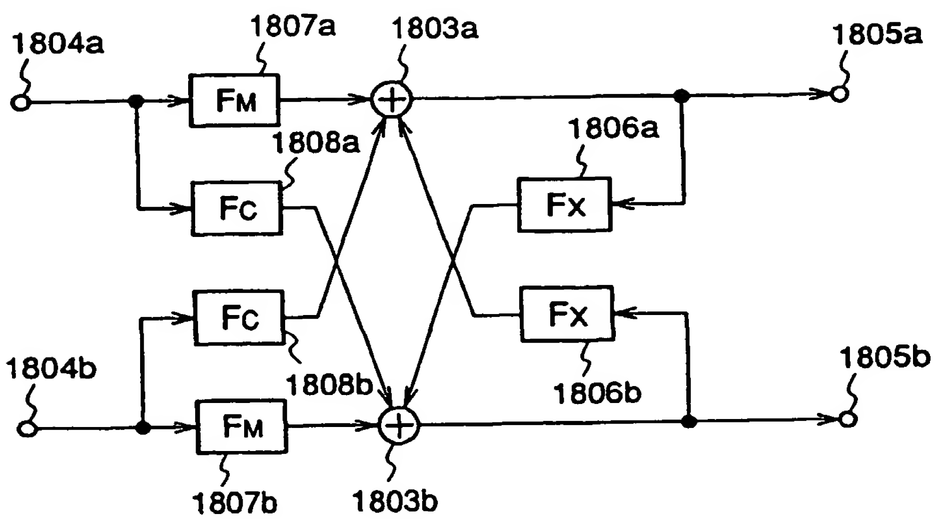


Fig.18 Prior Art



Prior Art

Fig.19 (a)

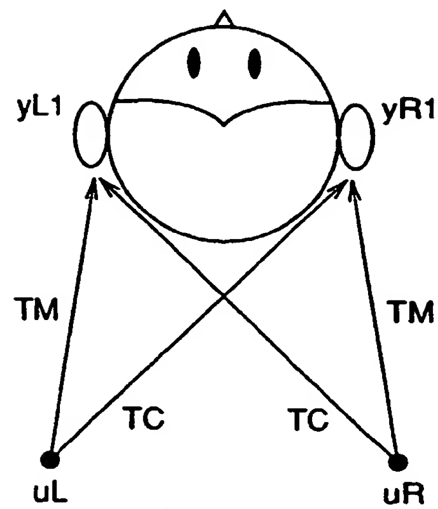
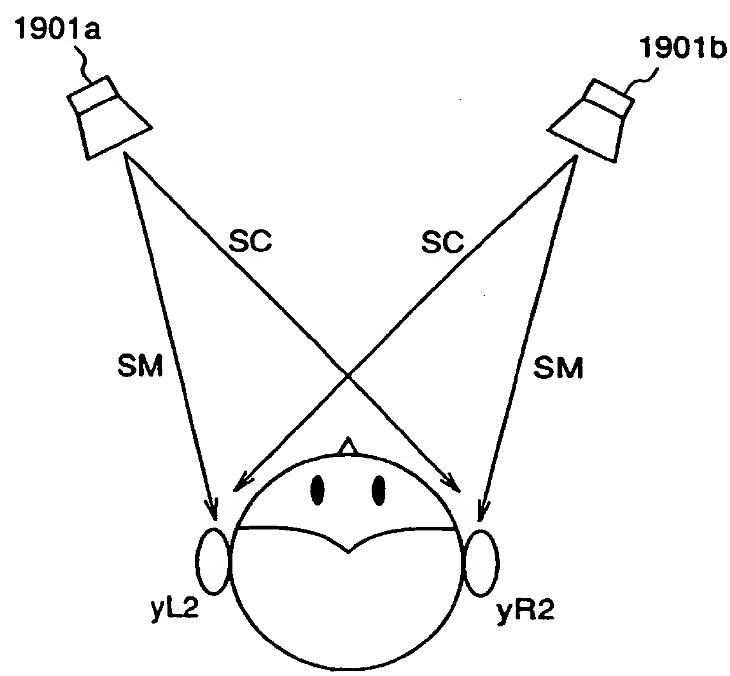


Fig.19 (b)



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(54) Apparatus for localization of sound image

(57) A sound image localization apparatus comprises crosstalk canceling means and direction localizing means, wherein first the crosstalk canceling means first subject an input sound signal to crosstalk cancellation, and then, the direction localizing means subject the processed signal to directional localization, whereby both crosstalk cancellation and directional localization share a signal to be processed, so the necessary amount of a storage device to hold the signal is reduced. That is, a reduction in circuit scale and calculation load can provide a sound image localization apparatus with low cost and high processing precision.

EP 0 889 671 A2 CORRIGENDUM *Issued on 01.09.1999 (bibliography updates included) - See p.9*

Description

FIELD OF THE INVENTION

The present invention relates to an apparatus for localization of a sound image and, more particularly, to an apparatus for localization of a sound image which receives a sound signal, subjects the sound signal to signal processing, localizes a virtual sound image, and outputs a sound image localization signal.

BACKGROUND OF THE INVENTION

A conventional stereophonic system controls sound image localization using a plural of (generally two) loudspeakers, conferring a realistic sensation to the hearing of a listener. The conventional system usually includes two laterally spaced loudspeakers in front of the listener, so a sound image is localized between them. Outside the two loudspeakers no sound image is localized in the system. To obtain the effect that a sound image is localized outside the two loudspeakers, i.e., the surround of the listener, for instance, a sound from the back of the listener, the system sometimes includes loudspeakers at the rear as well as the two loudspeakers in front of the listener.

The development of technology for digitizing audio and hardware for DSP (Digital Signal Processor) facilitates various signal processing. Owing to this, the system using two loudspeakers in front of the listener can localize a sound image at any position around the listener, such as the side and rear of the listener.

The prior art sound image localization apparatus has been discussed in "A Study of Cancellation of Crosstalk Signal for Sound Field Control", Collective Papers of Spring Convention of Japanese Acoustical Society, 1996, pp 549-550 (hereinafter referred to as bibliography 1).

Figs. 19(a) and 19(b) are diagrams for explaining about sound image localization. Fig. 19(a) shows a sound image to be localized in a virtual way. Fig. 19(b) shows a system using two loudspeakers. In this case, it is assumed that the positions of virtually localized sound images, and the positions of the two loudspeakers are left-and-right symmetrical with respect to the listener.

In the sound image localization apparatus, a direction of a virtual position is localized and crosstalk is canceled by signal processing using a head related transfer function indicating transfer characteristics of sound from a sound source to the listener's head or ear.

Here, in case like Fig. 19(b), a crosstalk signal is a signal transferred from a left loudspeaker to a right ear, or from a right loudspeaker to a left ear. A signal is generated for canceling the crosstalk signal.

In the virtual environment achieved by this system as shown in Fig. 19(a), sound signals uL and uR are radiated from the positions of virtual sound images located laterally at the back of the listener. Reference numerals, yL1 and yR1, indicate sound pressures given to left and right ears, respectively. Because of the left-and-right symmetry, transfer of sound from the left virtual position to the left ear is the same as that from the right virtual position to the right ear. Ahead related transfer function showing this transfer characteristics is indicated by TM. The transfer of sound from the left virtual position to the right ear and that from the right virtual position to the left ear are represented by the same head related transfer function TC. The relation between the sound pressures and the functions are represented by

$$yL1 = TM \cdot uL + TC \cdot uR \qquad (1\text{-}1)$$

and

$$yR1 = TC \cdot uL + TM \cdot uR \qquad (1\text{-}2).$$

On the other hand, in a system shown in Fig. 19(b), left and right loudspeakers 1901a and 1901b radiate sound signals xL and xR, respectively. Sound pressures given to the left and right ears of the listener are yL2 and yR2, respectively. As they are left-and-right symmetrical, the transfer of sound from the left loudspeaker position to the left ear and that from the right loudspeaker position to the right ear are represented by the same head related transfer function SM. The transfer of sound from the left loudspeaker position to the right ear and that from the right loudspeaker position to the left ear are also represented by the same head related transfer function SC. The relation between those sound pressures and those functions are

$$yL2 = SM \cdot xL + SC \cdot xR \qquad (2\text{-}1)$$

and

$$yR2 = SC \cdot xL + SM \cdot xR \qquad (2\text{-}2).$$

In this system, to localize the positions of the sound images shown in Fig. 19(a) using acoustics output from the loudspeakers 1901a and 1901b, the following equations must be satisfied,

$$yL1 = yL2 \tag{3-1}$$

and

$$yR1 = yR2 \tag{3-2}.$$

The equations 3-1, 1-1, and 2-1 lead to the following equation 4-1, and the equations 3-2, 1-2, and 2-2 lead to the following equation 4-2,

$$TM \cdot uL + TC \cdot uR = SM \cdot xL + SC \cdot xR \tag{4-1}$$

and

$$TC \cdot uL + TM \cdot uR = SC \cdot xL + SM \cdot xR \tag{4-2}.$$

The solution to xL and xR is obtained from the equations 4-1 and 4-2. If assumed that, the gain being represented by $|^{*}|$,

$$|(SC/SM)^2| << 1 \tag{5},$$

xL and xR are approximated by

$$xL \sim (FM + FC \cdot FX) \cdot uL + (FC + FM \cdot FX) \cdot uR \tag{6-1}$$

and

$$xR \sim (FC + FM \cdot FX) \cdot uL + (FM + FC \cdot FX) \cdot uR \tag{6-2},$$

where

$$FM = TM/SM \tag{7-1},$$

$$FC = TC/SM \tag{7-2},$$

and

$$FX = -SC/SM \tag{7-3}.$$

The other solution is possible, that is,

$$xL = FM \cdot uL + FC \cdot uR + FX \cdot xR \tag{8-1}$$

and

$$xR = FC \cdot uL + FM \cdot uR + FX \cdot xL \tag{8-2}$$

are obtained. In the equations 8-1 and 8-2, the first and second terms on the right side indicate the directions of sound images, that is, they localize the directions. The third term on the right side cancels a crosstalk component.

Using the above relations, a conventional sound image localization apparatus is constructed, shown in Fig. 17(a). The conventional sound image localization apparatus comprises a crosstalk canceling means 1701, direction localizing means 1702a and 1702b, and adders 1703a and 1703b. Sound signals are input through input terminals 1704a and 1704b. Signals resulting from subjecting the input sound signals to signal processing are output through output terminals 1705a and 1705b.

The direction localizing means 1702a and 1702b process the sound signals input through the input terminals 1704a and 1704b to generate signals indicating the directions of sound image positions, respectively. The adders

1703a and 1703b add input signals. The crosstalk canceling means 1701 removes a crosstalk component of an input signal.

Fig. 17(b) is a diagram illustrating an example of detailed structure of the conventional sound image localization apparatus. The crosstalk canceling means 1701 shown in Fig. 17(a) comprises crosstalk canceling signal generating filters 1706a and 1706b, and adders 1703c and 1703d. The direction localizing means 1702a and 1702b shown in Fig. 17(a) comprise main-path filters 1707a and 1707b, and crosstalk-path filters 1708a and 1708b, respectively. The combination of the main-path filter and the crosstalk-path filter is sometimes called a direction localizing filter.

The prior art sound image localization apparatus generates the outputs xL and xR according to the expressions 6-1 and 6-2. A description will be given of how the sound image localization apparatus works.

Left and right input sound signals are input through the input terminals 1704a and 1704b, respectively. The first input sound signal input through the input terminal 1704a is input to the main-path filter 1707a and the crosstalk-path filter 1708a. The main-path filter 1707a multiplies the input signal by the coefficient shown in the equation 7-1. The crosstalk-path filter 1708a multiplies the input signal by the coefficient shown in the equation 7-2. The outputs of the main-path filter 1707a and the crosstalk-path filter 1708a are input to the adders 1703a and 1703b, respectively.

Similarly, the second input sound signal input through the input terminal 1704b is input to the main-path filter 1707b and the crosstalk-path filter 1708b, where the input signal is multiplied by the coefficients expressed by 7-1 and 7-2, respectively. The outputs of the main-path filter 1707b and the crosstalk-path filter 1708b are input to the adders 1703b and 1703a, respectively.

The adders 1703a and 1703b each add input signals. The adder 1703a outputs a result of the addition to the adder 1703c and the crosstalk canceling signal generating filter 1706a. The crosstalk canceling signal generating filter 1706a multiplies the input signal by the coefficient represented by the equation 7-3 to produce a crosstalk canceling signal signal, and outputs the signal to the adder 1703d.

Similarly, the adder 1703b outputs a result of the addition to the adder 1703d and the crosstalk canceling signal generating filter 1706b. The crosstalk canceling signal generating filter 1706b multiplies the input signal by the coefficient represented by the equation 7-3 to produce a crosstalk canceling signal, and outputs the signal to the adder 1703c.

The adders 1703c and 1703d each add results of addition by the adders 1703a and 1703b to the crosstalk canceling signal having phase almost equivalent to the inversed phase of the result of the addition, respectively. Thus, signals represented by the expressions 6-1 and 6-2, of which crosstalk components are removed, are output through the output terminals 1705a and 1705b, respectively.

In the sound image localization apparatus having the structure shown in Fig. 17(b), the output of a crosstalk canceling signal generating filter on either channel (for example, 1706a) is output to the output side of the other channel (the adder 1703d on the side having the output terminal 1705b). This structure is called feedforward.

Disclosed is an apparatus, which is a second example realizing the conventional sound image localization apparatus, in Japanese Patent Published Application No. Hei 9-233599 (1997) (hereinafter referred to as bibliography 2).

Fig. 18 is a diagram showing a detailed structure of a second example of the sound image localization apparatus. The crosstalk canceling means 1701 in Fig. 17(a) comprises crosstalk canceling signal generating filters 1806a and 1806b, and adders 1803a and 1803b. The direction localizing means 1702a and 1702b in Fig. 17(a) comprise main-path filters 1807a and 1807b, and crosstalk-path filters 1808a and 1808b, respectively. The adders 1803a and 1803b are the same as the adders 1703a and 1703b in Fig. 17(a), and also part of the crosstalk canceling means 1701.

The sound image localization apparatus shown in Fig. 18 generates outputs xL and xR according to the equations 8-1 and 8-2. With the different structure from that shown in Fig. 17(b), the sound image localization apparatus is called a feedback type, because a crosstalk canceling signal generating filter (for instance, 1806a) on either channel outputs a signal to the input side on the other channel (the adder 1803b). A description will be given of how the sound image localization apparatus operates.

Left and right input sound signals are input through the input terminals 1804a and 1804b, respectively. The first input sound signal input through the input terminal 1804a is input to the main-path filter 1807a and the crosstalk-path filter 1808a. The main-path filter 1807a multiplies the input signal by the coefficient represented by the equation 7-1, and outputs the result to the adder 1803a. The crosstalk-path filter 1808a multiplies the input signal by the coefficient represented by the equation 7-2, and outputs the result to the adder 1803b. In a similar way, the right input sound signal input through the input terminal 1804b is input to the main-path filter 1807b and the crosstalk-path filter 1808b, where the signals are multiplied by coefficients represented by the equations 7-1 and 7-2, and the results are output to the adders 1803b and 1803a, respectively.

The adders 1803a and 1803b each add the input signals. The adder 1803a outputs a result of the addition to the crosstalk canceling signal generating filter 1806a. The crosstalk canceling signal generating filter 1806a multiplies the input signal by the coefficient represented by the equation 7-3 to generate a crosstalk canceling signal, and outputs it to the adder 1803b. Similarly, the adder 1803b outputs a result of the addition to the crosstalk canceling signal generating filter 1806b. The crosstalk canceling signal generating filter 1806b multiplies the input signal by the coefficient rep-

resented by the equation 7-3 to generate a crosstalk canceling signal, and outputs it to the adder 1803a.

The adders 1803a and 1803b add the outputs of the direction localizing filter, and further add a result of the addition to the crosstalk canceling signal having phase almost equivalent to the inversed phase of the result of the addition, to remove a crosstalk component. Hence, signals represented by the equations 8-1 and 8-2 are output through the output terminals 1805a and 1805b.

As hereinbefore described, in the sound image localization apparatus in accordance with the first embodiment, multiple cancellation, in which the generation of a crosstalk canceling signal and the crosstalk cancellation using the generated signal are repeated, becomes possible. Compared with the first example, i.e., the feedforward type apparatus shown in Fig. 17(a), the adverse effect of sound diffraction of a low-frequency component of a sound signal is reduced, thereby solving the first problem of the prior art and improving low-frequency characteristics.

As described above, the conventional sound image localization apparatus can localize a sound image over a wide range by localization of a virtual sound image and compensation of a crosstalk component. However, when trying to realize the foregoing sound image localization apparatus by a computer system using a CPU and a DSP, the following several problems arise.

The first problem is about a memory used for temporary storage in operational processing. The amount and performance of a memory in a computer system limit operational processing. The main constraints on memory are

(A) constraint on the amount of memory for storage of sound signal data,
(B) constraint on the amount of memory for storage of coefficients of a filter, and
(C) constraint on accessing time of a memory.

As to (A) and (B), when the number of words showing the amount of memory is small, the number of taps indicating the order of a filter is limited to an insufficient size, resulting in a reduction in precision of operational processing.

Furthermore, when the amount of a high-speed internal memory included in a computer system is limited, if a relatively low-speed external memory (RAM) assists to secure a required precision of operational processing, the problem (C) arises. Because frequent memory accesses occur in operational processing realizing the above-described digital filter performing directional localization and crosstalk cancellation, a simple supplement of the external memory having a low accessing speed hardly solves the constraint on the amount of memory.

The second problem relates to a controller included in a computer system, such as DSP. The processing speed of the controller limits operational processing. When the processing speed is not sufficient, the order of a digital filter is limited, thereby reducing precision in operational processing.

The third problem is that it is difficult for the conventional sound image localization apparatus to deal with changes in setting of an acoustic system using it. The second example of the prior art sound image localization apparatus shown in Fig. 18, i.e., the feedback type, improves the reproducibility of a low-frequency component compared with the feedforward type. However, when a loudspeaker with a small diameter is used in an acoustic system to which the sound image localization apparatus is applied, the large energy of the low-frequency range causes sound distortion. If a filter cutting off a low-frequency component is adopted to improve this point, the additional filter increases the circuit scale and the cost.

Further, when loudspeakers are rearranged in the acoustic system in such a way as that the angle the loudspeakers attain changes, the conventional sound image localization apparatus modifies all the parameters of the filter FX. Thus, to adapt to changes in setting of the acoustic system, parameters for each setting are required to be held. The requirement of storage of parameters increases the amount of memory.

As the three problems indicate, the prior art sound image localization apparatus has a difficulty in improving low-frequency characteristics. Furthermore, when implemented in a computer system, the apparatus requires the large amount of memory and the high-speed of processing, thereby making it difficult to realize both precision of controlling sound image localization and a reduction in costs of the computer system.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision while limiting an increase in the circuit scale caused by requirement of the amount of memory.

It is another object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision by additionally exploiting an external memory when the amount of a high-speed internal memory is limited.

It is still another object of the present invention to provide a sound image localization apparatus realizing sound image localization with good precision by simplifying operational processing when the computer system does not include a high-performance DSP.

It is yet another object of the present invention to provide a sound image localization apparatus flexibly coping with changes in setting of the acoustic system, without increasing the circuit scale.

Other objects and advantages of the present invention will become apparent from the detailed description desired hereinafter; it should be understood, however, that the detailed description and specific embodiment are desired by way of illustration only, since various changes and modifications within the scope of the invention will become apparent to those skilled in the art from this detailed description.

According to a second aspect of this invention, there is provided the sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for generating a crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
direction localizing means for localizing the direction of a virtual sound source position by processing the signal subjected to crosstalk cancellation in the crosstalk canceling means.

As a result, the apparatus first performs crosstalk cancellation to an input sound signal, and then, performs directional localization to the sound signal.

According to a second aspect of this invention, there is provided the sound image localization apparatus of the first aspect wherein

the crosstalk canceling means comprise first and second crosstalk canceling signal generating filters, and first and second adders, the first adder adding a first sound signal and a signal generated by the second crosstalk canceling signal generating filter, and the second adder adding a second sound signal and a signal generated by the first crosstalk canceling signal generating filter;
the direction localizing means comprise first and second main-path filters, first and second crosstalk-path filters, and first and second adders, the first adder adding a signal processed by the first main-path filter and a signal processed by the second crosstalk-path filter, and the second adder adding a signal processed by the second main-path filter and a signal processed by the first crosstalk-path filter.

As a result, the apparatus first performs crosstalk cancellation to an input sound signal using a signal generated by a crosstalk canceling signal generating filter, and then, performs directional localization to the sound signal using a main-path filter and a crosstalk-path filter.

According to a third aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for including a comb filter to generate the crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation using a signal generated by a crosstalk canceling signal generating filter including a comb filter of which the coefficients are the same.

According to a fourth aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means for generating a crosstalk canceling signal generated at a certain time, holding the crosstalk canceling signal, delaying the crosstalk canceling signal held, holding the plurality of crosstalk canceling signals delayed, and multiplying some of the plurality of crosstalk canceling signals held by a predetermined coefficient to generate the crosstalk canceling signal at a time following the certain time; and
direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation using a singal generated a crosstalk canceling signal generating filter including a circuit replacing a comb filter, of which the processing load is reduced.

According to a fifth aspect of this invention, there is provided the sound image localization apparatus of any of the third and fourth aspects wherein

the apparatus further comprises a low-pass filter processing a signal input to or output from the crosstalk canceling

means.

As a result, the apparatus performs crosstalk cancellation to a signal, of which a high-frequency component is removed, using a singal generated a crosstalk canceling signal generating filter including a comb filter or a circuit replacing a comb filter.

According to a sixth aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a switch switching the crosstalk canceling signal generated by the crosstalk canceling signal generating filter to the output side of the crosstalk canceling signal generating filter or to the input side of the crosstalk canceling signal generating filter; and

direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus switches feedback processing and feedforward processing.

According to a seventh aspect of this invention, there is provided a sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, the apparatus comprising:

crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a delaying unit delaying a signal input to or output from the crosstalk canceling signal generating filter by various times; and

direction localizing means for localizing the direction of a virtual sound source position.

As a result, the apparatus performs crosstalk cancellation by changing the amount of an initial delay.

According to an eighth aspect of this invention, there is provided a sound image localization apparatus receiving an input sound signal to be localized in a first direction, and an input sound signal to be localized in a second direction, performing signal processing to the input sound signals, localizing virtual sound images, and outputting sound image localization signals, the apparatus comprising:

crosstalk canceling means comprising a first filter, a second filter, and a switch switching first and second modes; in the first mode the first filter functioning as a filter generating the crosstalk canceling signal, and in the second mode the second filter functioning as a filter generating the crosstalk canceling signal while the first filter functioning as a filter localizing the second direction; and

direction localizing means for localizing the direction of a virtual sound source position.

As a result, a crosstalk canceling signal generating filter for localizing a sound image to be localized in a first direction, and a crosstalk canceling signal generating filter for localizing a sound image to be localized in a second direction, are switched.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1(a) and 1(b) are block diagrams showing structures of a sound image localization apparatus in accordance with a first embodiment of this invention.

Fig. 2 is a diagram showing an example of a structure of a filter included in the sound image localization apparatus of the first embodiment.

Fig. 3 is a diagram showing an example of a structure of a filter included in the sound image localization apparatus of the first embodiment.

Fig. 4 is a block diagram showing a structure of an application example of the sound image localization apparatus of the first embodiment.

Fig. 5 is a block diagram showing a structure of a sound image localization apparatus in accordance with a second embodiment of this invention.

Fig. 6 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.

Figs. 7(a) and 7(b) are graphs showing frequency characteristics of a filter used in the second embodiment to explain how the filter works.

Fig. 8 is a block diagram showing a structure of an application example of the sound image localization apparatus

of the second embodiment.

Fig. 9 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.

Fig. 10 is a block diagram showing a structure of an application example of the sound image localization apparatus of the second embodiment.

Fig. 11 is a block diagram showing a structure of a sound image localization apparatus in accordance with a third embodiment of this invention.

Fig. 12 is a block diagram showing a structure of a sound image localization apparatus in accordance with a fourth embodiment of this invention.

Fig. 13 is a block diagram showing a structure of an application example of the sound image localization apparatus of the fourth embodiment.

Fig. 14 is a block diagram showing a structure of an application example of the sound image localization apparatus of the fourth embodiment.

Fig. 15 is a block diagram showing a structure of a sound image localization apparatus in accordance with a fifth embodiment of this invention.

Fig. 16 is a block diagram showing a structure of a sound image localization apparatus in accordance with a sixth embodiment of this invention.

Figs. 17(a) and 17(b) are block diagrams showing structures of a first example of a prior art sound image localization apparatus.

Fig. 18 is a block diagram showing a structure of a second example of a prior art sound image localization apparatus.

Figs. 19(a) and 19(b) are diagrams for explaining sound image localization.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Embodiment 1]

A sound image localization apparatus in accordance with a first embodiment of this invention reduces the necessary amount of memory by subjecting a signal to directional localization after performing crosstalk cancellation to the signal.

Fig. 1(a) is a block diagram showing a structure of the sound image localization apparatus of the first embodiment. As shown in the figure, the sound image localization apparatus comprises a crosstalk canceling means 101, and direction localizing means 102a and 102b, adders 103a and 103b. The apparatus receives input sound signals through input terminals 104a and 104b, subjects the input signals to signal processing, and outputs the resulting signals through output terminals 105a and 105b.

The crosstalk canceling means 101 removes crosstalk components from the input signals input through the input terminals 104a and 104b. The direction localizing means 102a and 102b process input sound signals to produce signals indicating the directions of sound images. The adders 103a and 103b add input signals.

The operational processing of the sound image localization apparatus will be explained. Initially, in addition to the equations 1-1 to 8-2 shown in the BACKGROUND OF THE INVENTION and Embodiment 1 sections, vL and vR are defined by

$$xL = FM \cdot vL + FC \cdot vR \tag{9-1}$$

and

$$xR = FC \cdot vL + FM \cdot vR \tag{9-2}$$

The equation 9-1 is substituted to the equation 8-1, and 9-2 is substituted to 8-2, and then

$$FM \cdot vL + FC \cdot vR = FM \cdot uL + FC \cdot uR + FX \cdot (FC \cdot vL + FM \cdot vR) \tag{10-1}$$

and

$$FC \cdot vL + FM \cdot vR = FC \cdot uL + FM \cdot uR + FX \cdot (FM \cdot vL + FC \cdot vR) \tag{10-2}$$

are obtained. From 10-1 and 10-2, FM and FC are eliminated, and then

$$vL = uL + FX \cdot vR \tag{11-1}$$

and

$$vR = uR + FX \cdot vL \tag{11-2}$$

are obtained.

The equations 11-1 and 11-2 mean that a crosstalk canceling means is required to be set up on the input side. The equations 9-1 and 9-2 mean that direction localizing means are required to be set up on the output side. Accordingly, the sound image localization apparatus of the first embodiment, as shown in Fig. 1(a), includes a crosstalk canceling means 101 on the input side, and direction localizing means 102a and 102b on the output side.

Fig. 1(b) is a diagram showing a detailed structure of a first example of the sound image localization apparatus of the first embodiment. The crosstalk canceling means 101 shown in Fig. 1(a) comprises crosstalk canceling signal generating filters 106a and 106b, and adders 103c and 103d in Fig. 1(b). The direction localizing means 102a and 102b shown in Fig. 1(b) comprise main-path filters 107a and 107b, and crosstalk-path filters 108a and 108b in Fig. 1(b), respectively. An explanation will be given of the operation of the first example of the sound image localization apparatus.

Left and right input sound signals uL and uR are input through input terminals 104a and 104b. In Fig. 1(b), the first input sound signal uL input through the input terminal 104a is input to the adder 103c. The right input sound signal uR input through the input terminal 104b is input to the adder 103d. Immediately after the sound image localization apparatus starts processing, the crosstalk canceling signal generating filters 106a and 106b don't generate any signals to be output to the adders 103c and 103d, so the adders 103c and 103d output input signals uL and uR as they are. The signals uL and uR are input to the crosstalk canceling signal generating filters 106a and 106b as signals vL and vR, respectively.

The crosstalk canceling signal generating filter 106a multiplies the input signal by the coefficient having a negative sign represented by the equation 7-3 to produce a crosstalk canceling signal, and outputs it to the adder 103d. The crosstalk canceling signal generating filter 106b performs a similar processing to produce a crosstalk canceling signal, and outputs it to the adder 103c.

The adder 103c adds the input sound signal uL and the crosstalk canceling signal to perform crosstalk cancellation, generating the signal vL represented by the equation 11-1. The generated signal vL is input to the main-path filter 107a and the crosstalk-path filter 108a. In a similar manner, the adder 103d generates the signal vR represented by 11-2, which is input to the main-path filter 107b and the crosstalk-path filter 108b.

The main-path filter 107a multiplies the input signal by the coefficient represented by the equation 7-1, and outputs the result to the adder 103a. The crosstalk-path filter 108a multiplies the input signal by the coefficient represented by the equation 7-2, and outputs the result to the adder 103b. The output of the main-path filter 107a is represented by the first term on the right side of the equation 9-1. The output of the crosstalk-path filter 108a is represented by the second term on the right side of the equation 9-2.

Similarly, the adder 103d adds the crosstalk canceling signal to the input sound signal uR to perform crosstalk cancellation. The resulting signal vR is input to the main-path filter 107b and the crosstalk-path filter 108b, where the signal is multiplied by the coefficients represented by the equations 7-1 and 7-2, respectively. The outputs of the main-path filter 107b and the crosstalk-path filter 108b are input to the adders 103b and 103a, respectively. The output of the main-path filter 107b is represented by the first term on the right side of the equation 9-2. The output of the crosstalk-path filter 108a is represented by the second term on the right side of the equation 9-1.

The adders 103a and 103b each add input signals, and output results of the addition through the output terminals 105a and 105b, respectively. Thus, the sound image localization apparatus in accordance with the first embodiment outputs signals xL and xR processed by directional localization, represented by the equations 9-1 and 9-2.

As described above, in the sound image localization apparatus in accordance with the first embodiment, because signals are subjected to crosstalk cancellation prior to directional localization, as shown in Fig. 1(b), the inputs of the crosstalk canceling signal generating filter (FX) and the direction localizing filter (FM and FC) are the same signal, vL or vR. Thus, for filtering, just those two signals are required to hold. Compared with the conventional sound image localization apparatus shown in Figs. 17(b) and 18, required to hold four kinds of signals, the amount of memory required to hold sound signals, described as the first problem in the BACKGROUND OF THE INVENTION section, can be reduced to a small size.

To explain the required amount of memory in the apparatus of the first embodiment, each structure of filters for crosstalk cancellation and directional localization will be shown.

There are two sorts of filters, FIR (Finite Impulse Response) accumulating input signals and IIR (Infinite Impulse Response) accumulating output signals as well as input signals. Either of the two kinds of filters can realize the sound image localization apparatus of the first embodiment. Fig. 2 is a diagram showing the first example of the apparatus in which the crosstalk canceling signal generating filters 106a and 106b, and the direction localizing filters 107a, 107b,

108a, and 108b are FIR filters. Fig. 2 shows another example in which each filt r shown in Fig. 1(b) is the concatenation of an FIR filter and an IIR filter.

In Fig. 2, the crosstalk canceling signal generating filter 106a included in the first example (Fig. 1(b)) of the sound image localization apparatus, comprises delaying units 111a and 111c to 111f, multiplier 110x1 to 110x5, and an adder 103i. The crosstalk canceling signal generating filter 106b comprises delaying units 111b and 111g to 111j, multipliers 110x6 to 110x10, and an adder 103j. The parts in Fig. 2 represented by the dashed lines, such as the multipliers 110x1 to 110x5 and the delaying units 111c to 111f, show that the number of multipliers or delaying units is variable.

The main-path filter 107a comprises delaying units 111c to 111f, multipliers 110m1 to 110m5, and an adder 103e. The main-path filter 107b comprises delaying units 111g to 111j, multipliers 110m6 to 110m10, and an adder 103f. The crosstalk-path filter 108a comprises delaying units 111c to 111f and 111n to 111p, multipliers 110c1 to 110c5, and an adder 103g. The crosstalk-path filter 108b comprises delaying units 111g to 111j and 111k to 111m, multipliers 110c6 to 110c10, and an adder 103h.

Multipliers 110a1 and 110a2 function as attenuators to prevent overflow in executing fixed point calculation. Delaying units 111k to 111p are employed to produce the time difference between both ears.

As the filters in Fig. 2 include the delaying units 111c to 111j, the crosstalk canceling signal generating filer and the direction localizing filter receive the same input signals, as signals vL or vR shown in Fig. 1(b). Hence, compared with the case where the input of each filter is held, it is possible to reduce the amount of memory required to hold signals.

Fig. 2 shows the example using IIR filters. In this example, a crosstalk canceling signal generating filter comprises IIR filter FXIs 112a and 112b. A main-path filter comprises IIR filter FMIs 113a and 113b. A crosstalk-path filter comprises IIR filter FCIs 114a and 114b. Those IIR filters are concatenated with the FIR filters shown in Fig. 2.

The portions of the main-path filter, the crosstalk-path filter, and the crosstalk canceling signal generating filter, constituted by FIR filters, are represented by FMF, FCF, and FXF, respectively. The FM, FC, and FX shown in the equations 7-1 to 7-3 are represented by

$$FM = FMF \cdot FMI \qquad (12\text{-}1),$$

$$FC = FCF \cdot FCI \qquad (12\text{-}2),$$

and

$$FX = FXF \cdot FXI \qquad (12\text{-}3).$$

Also in this case, similar to the structure shown in Fig. 2, the FIR filter portions share an input, thereby making it possible to reduce the required amount of memory. It should be noted that the reduction is not as much as that in the case where only the FIR filters are employed.

Fig. 4 is a diagram illustrating a second example of a detailed structure of a sound image localization apparatus, shown in Fig. 1(a), in accordance with the first embodiment. As shown in the figure, the second example of the sound image localization apparatus comprises adders 103a to 103d, crosstalk canceling signal generating filters 106a and 106b, main-path filters 107a and 107b, crosstalk-path filters 108a and 108b, high-frequency main-path filters 117a and 117b, subsampling circuits 115a and 115b, and band compositing circuits 116a and 116b. As in the first example shown in Fig. 1(b), input sound signals are input through the input terminals 104a and 104b, and subjected to signal processing, and the resulting signals are output through the output terminals 105a and 105b.

The subsampling circuits 115a and 115b subject input signals to prescribed subsampling to produce a low-frequency component and a high-frequency component. The band compositing circuits 116a and 116b subject input signals to prescribed composition to produce composite signals. The high-frequency main-path filters 117a and 117b operate in a similar way to the main-path filters 107a and 107b. The adders 103a to 103d, the crosstalk canceling signal generating filters 106a and 106b, main-path filters 107a and 107b, and the crosstalk-path filters 108a and 108b are similar to those in the first example.

The operation of the second example of the sound image localization apparatus of the first embodiment will be described.

Left and right input sound signals are input through the input terminals 104a and 104b. The first input sound signal input through the input terminal 104a is input to the subsampling circuit 115a. The subsampling circuit 115a subsamples the first input sound signal to a high-frequency component and a low-frequency component, and outputs the high-frequency component to the high-frequency main-path filter 117a, and the low-frequency component to the adder 103c. The subsampling circuit 115b operates in a similar way.

The high-frequency main-path filters 117a and 117b multiply the input high-frequency components by the coefficient represented by the equation 7-1, and output the resulting signals to the band compositing circuits 116a and 116b, respectively.

The low-frequency component of the input sound signal is subjected to crosstalk cancellation and directional localization in a similar manner to the first example, and the resulting signals are input to the band compositing circuits 115a and 115b, respectively. The band compositing circuits 115a and 115b composite a signal resulting from processing the high-frequency component with the high-frequency filter, and a signal resulting from processing the low-frequency component by directional localization after crosstalk cancellation, and output the composite signals through the output terminals 105a and 105b, respectively.

As is clear from the above, a second example of the sound image localization apparatus subjects only the low-frequency component of the input signal to crosstalk cancellation. In general, the high-frequency component of an input signal is seriously affected by a slight shift of the head of a listener and differences among individuals, so that the benefit of crosstalk cancellation is little for the high-frequency component. Therefore, a second example of the sound image localization apparatus processes the high-frequency component only with the main-path filter. Thus, because the target of crosstalk cancellation is only the low-frequency component, the number of sampling frequency can be reduced, thereby making it possible to make the sizes of filter circuits in Figs. 3 and 4 smaller without reducing the precision of sound image localization.

As hereinbefore pointed out, the sound image localization apparatus in accordance with the first embodiment, as shown in Fig. 1(a), comprises a crosstalk canceling means 101 on the input side, and direction localizing means 102a and 102b on the output side. Thereby, each filter included in the crosstalk canceling means 101 and the direction localizing means 102a and 102b shares an input signal by using delaying units as shown in Figs. 2 and 3. As a result, the amount of memory required to hold a sound signal is reduced while sound image localization can be satisfactory.

[Embodiment 2]

A sound image localization apparatus in accordance with a second embodiment of this invention employs a comb filter.

Fig. 5 is a block diagram showing a structure of a first example of the sound image localization apparatus of the second embodiment. The outline of the structure of the sound image localization apparatus is similar to the structure of the feedback type apparatus in the prior art shown in Fig. 18. As shown in Fig. 5, the sound image localization apparatus comprises adders 503a, 503b, 503e, and 503f, main-path filters 507a and 507b, crosstalk-path filters 508a and 508b, delaying units 511a to 511j, and multipliers 510x1 to 510x10. Input sound signals are input through input terminals 504a and 504b, and subjected to signal processing, and the resulting signals are output through output terminals 505a and 505b. As in Fig. 2 and so on, dashed lines on rows of the delaying units and the multipliers represent an arbitrary number of the delaying units and the multipliers in Fig. 5.

In Fig. 5, the crosstalk canceling signal generating filter 106a shown in Fig. 18 comprises the delaying units 511a, 511c to 511f, the multipliers 510x1 to 510x5, and the adder 503e. The crosstalk canceling signal generating filter 106b shown in Fig. 18 comprises the delaying units 511b, 511g to 511j, the multipliers 510x6 to 510x10, and the adder 503f. All the coefficients of the multipliers 510x1 to 510x10 are possible to be the same, which makes the filter a comb type. Therefore, when using a comb filter, it is possible to reduce the amount of memory, required to hold the coefficient, described in the BACKGROUND IN THE INVENTION section, as the first problem (B).

The operation of the sound image localization apparatus of the second embodiment is similar to that of the feedback type sound image localization apparatus of the first embodiment.

Figs. 7(a) and 7(b) are graphs for explaining frequency characteristics of a filter. Fig. 7(a) shows amplitude characteristics. Fig. 7(b) indicates phase characteristics. In either figure, a solid line represents characteristics of the comb filter used in the second embodiment, and a dashed line represents characteristics obtained from the ratio of head related transfer functions. In general, a comb filter has linear phase type low-pass characteristics. As is apparent from the figure, both the characteristics are similar to each other in a low-frequency range of the amplitude and phase characteristics. As described in the first embodiment, cancellation is particularly effective in a low-frequency range of a sound signal. Because the characteristics of the comb filter is approximate to that obtained from the head related transfer function in the low-frequency range, the comb filter operates well for the low-frequency range. For a high-frequency range in which the two characteristics differ, crosstalk cancellation is hardly effective, so the influence of differences between the two characteristics is little.

Fig. 6 is a block diagram showing a structure of a second example of the sound image localization apparatus of the second embodiment. As shown in Fig. 6, this example includes a first example of the sound image localization apparatus, and further comprises low-pass filters 620a and 620b. The low-pass filter 620a comprises an adder 603c, multipliers 610f1 and 610f2, and a delaying unit 611a. The low-pass filter 620b comprises an adder 603d, multipliers 610f3 and 610f4, and a delaying unit 611b.

As to the operation of the sound image localization apparatus, the high-frequency components of signals input to the crosstalk canceling signal generating filters 106a and 106b shown in Fig. 18 are removed, and the other operation is similar to that of the first example. As hereinbefore pointed out, in generating a crosstalk canceling signal, the high-

frequency component of a sound signal is not necessarily taken into consideration. In this example, the high-frequency component is not the target of processing, thereby making it possible to improve the precision of sound localization better than the first example. Note that the scale of the circuit of the second example becomes slightly larger than that of the first example by the low-pass filter.

Although in the second example the low-pass filter is disposed in front of the crosstalk canceling signal generating filter, i.e., on the input side, the low-pass filter can be disposed at the rear of the crosstalk canceling signal generating filter, i.e., on the output side, thereby making possible the same effect.

Fig. 8 is a diagram showing a structure of a third example of the sound image localization apparatus of the first embodiment. As shown in the figure, this example employs a comb filter, similar to that in the first example, but having FIRs of which the number of taps is small. In the structure shown in Fig. 8, the number of taps is two, and all the coefficients can be set to, for instance, -0.46. In this case, the filter becomes a filter having linear phased low-pass characteristics. This sound image localization apparatus operates in a similar way to the first example.

In an acoustic system using the sound image localization apparatus, when the distance between two loudspeakers is set to be short, for example, the angle the loudspeakers attain is 10 to 20 degrees, the ratio of head related transfer functions shown in Fig. 19(b), i.e., SC/SM, becomes close to 1. Therefore, considering the stability of sound image localization, and a reduction in a high-frequency component due to the sound diffraction of a sound signal, a filter having a small number of taps has good approximation in this case. In the case, the apparatus having the structure shown in Fig. 8 can reduces the amount of memory required to store the coefficient further than the first example shown in Fig. 5. As a result, the amount of data held by the delaying unit becomes small, and it is possible to make the scale of the circuit smaller.

Figs. 9 and 10 are diagrams showing a structure of a fourth example of the sound image localization of the second embodiment. As shown in Fig. 9, this example of the sound image localization apparatus includes a third example of the apparatus, and further comprises high-frequency main-path filters 917a and 917b, subsampling circuits 915a and 915b, and band compositing circuits 916a and 916b. These are similar to those shown in the second example of the first embodiment, i.e., the high-frequency main-path filters 117a and 117b, the subsampling circuits 115a and 115b, and the band compositing circuits 116a and 116b. The same with high-frequency main-path filters 1017a and 1017b, subsampling circuits 1015a and 1015b, and band compositing circuits 1016a and 1016b, shown in Fig. 10.

As to the operation of this example of the sound image localization apparatus, subsampling and band composition are similar to those in the first embodiment, and the other processes are similar to those in the second embodiment. Therefore, similar to the second example in the first embodiment and the third example in the first embodiment, this example of the sound image localization apparatus can reduce the required amount of memory and make the scale of the circuit smaller.

The crosstalk canceling signal generating filter as the FIR filter having two taps similar to the third example is disposed between the direction localizing filter and the band compositing circuit in the structure shown in Fig. 9, while being disposed at the rear of the band compositing circuit, i.e., on the output side, in the structure shown in Fig. 10. However, the crosstalk canceling signal generating filter may be disposed in front of the subsampling circuit, i.e., on the input side, or between the subsampling circuit and the direction localizing filter, and may receive only the low-frequency component output from the subsampling circuit as the target of processing, resulting in the similar effect.

As described above, the sound image localization apparatus in accordance with the second embodiment includes the comb filters in which the coefficients of the multipliers 510x1 to 510x10 shown in Fig. 5 are the same, whereby the operation using the filters requires only one parameter, i.e., the coefficient, and therefore, the amount of memory for holding the coefficient is reduced while making possible a high level of sound image localization.

Although in the second embodiment the outline of the structure is the same as the feedback type sound image localization apparatus shown in Fig. 18, the feedforward type sound image localization apparatus shown in Fig. 17(b) may be used, or a comb filter can be used for the sound image localization apparatus of the first embodiment shown in Fig. 1(b), resulting in the same effect.

[Embodiment 3]

A sound image localization apparatus in accordance with a third embodiment of this invention employs a circuit including delay buffers and accumulation registers (or memories) instead of comb filters of the second embodiment.

Fig. 11 is a block diagram showing a structure of the sound image localization apparatus of the third embodiment. The outline of the structure of the sound image localization apparatus of the third embodiment includes the same feedback structure as the prior art shown in Fig. 18, similar to the second embodiment. As shown in Fig. 11, the sound image localization apparatus comprises adders 1103a, 1103b, 1103c, and 1103d, main-path filters 1107a and 1107b, crosstalk-path filters 1108a and 1108b, delaying units 1111a to 1111j, and multipliers 1110f1 to 1110f4, 1110x1, 1110x5, 1110x6, and 1110x10. Input sound signals are input through input terminals 1104a and 1104b, and subjected to signal processing, and the resulting signals are output through output terminals 1105a and 1105b. As in Fig. 2,

dashed lines in the rows of the delaying units represent an arbitrary number of the delaying units.

In the figure, the portion including the adder 1103c, the multipliers 1110f1 and 1110f2, and the delaying unit 1111m, and the portion including the adder 1103d, the multipliers 1110f3 and 1110f4, and the delaying unit 1111n constitute low-pass filters similar to that in the second example of the second embodiment. In place of the comb filters constituting the crosstalk canceling signal generating filters (1806a and 1806b in Fig. 18), the delaying units 1111a, 1111b, 1111c to 1111f, and 1111g to 1111j, the multipliers 1110x1, 1110x5, 1110x6, and 1110x10, and the adders 1103e to 1103h are included in the sound image localization apparatus of the third embodiment.

The comb filter included in the apparatus of the second embodiment shown in Fig. 5 performs the operation equivalent to calculating the average of data held in the delaying units 511c to 511f at a time so as to generate a crosstalk canceling signal at the time. Accordingly, based on the crosstalk canceling signal obtained at a certain time, the oldest among the data is reduced to one n-th, and one n-th of the newest data is added to the data. Thereby, a crosstalk canceling signal at a next time is obtained.

In the sound image localization apparatus shown in Fig. 11, the delaying units 1111a and 1111b hold immediately previous signals. Among data held by the delaying units 1111c to 1111f and 1111g to 1111j, the oldest data, i.e., the data held in the delaying units 1111f and 1111j having maximum delay in Fig. 11, are multiplied by one n-th in the multipliers 1110x5 and 1110x10, and the results are subtracted from the immediately previous signals by the adders 1103g and 1103h, respectively. Among the data held by the delaying units, the newest data, i.e., the data held in the delaying units 1111c and 1111g having minimum delay in Fig. 11, are multiplied by one n-th in the multipliers 1110x1 and 1110x6, and the results are added to the results of the subtraction by the adders 1103e and 1103f. The results of the addition are crosstalk canceling signals similar to that is obtained from the operation of the comb filter. The generated signals are held by the delaying units 1111a and 1111b to generate signals at a next time.

In the sound image localization apparatus of the third embodiment, the data held in the delaying units 1111c to 1111f and 1111g to 1111j are accessed only when the oldest data are taken and when the newest data are written. Since the delaying unit included in the comb filter of the second embodiment is frequently accessed, a high-speed memory is required. In contrast, a relatively low-speed memory can be employed for the delaying unit included in the third embodiment. The amounts of multiplication and addition are further reduced in the third embodiment than in the second embodiment. Thus, the sound image localization apparatus in accordance with the third embodiment solves the access time problem of a memory, i.e., (C) of the first problem, and the processing speed problem, i.e., the second problem.

As explained above, the sound image localization apparatus of the third embodiment includes delay buffers (the delaying units 1111c to 1111f and 1111g to 1111j in Fig. 11) and accumulation registers (the delaying units 1111a and 1111b in Fig. 11) as filters for crosstalk cancellation in place of the comb filter. Thereby, the incidence of access to a memory, and the loads of addition and multiplication are reduced. As a result, in a computer system implementing the sound image localization apparatus, even when the amount of a high-speed memory and the processing speed of a processor are limited, a high level of sound image localization is possible.

Similar to the first embodiment, the outline of the structure in the third embodiment is the same feedback type sound image localization apparatus as shown in Fig. 18. However, the feedforward type apparatus shown in Fig. 17 (b) is possible, and a circuit substituting the comb filter can be employed in the apparatus of the first embodiment shown in Fig. 1(b).

[Embodiment 4]

A sound image localization apparatus in accordance with a fourth embodiment of this invention can localize a sound image by switching the apparatus to feedforward or feedback.

Fig. 12 is a diagram showing a structure of a first example of the sound image localization apparatus of the fourth embodiment. As shown in the figure, the sound image localization apparatus comprises the apparatus shown in Fig. 18 and, further, adders 1203c and 1203d, and switches 1218a and 1218b.

Fig. 12 shows a case where the switches 1218a and 1218b both turn to feedback (an FB side in the figure). In this situation, crosstalk canceling signals generated by crosstalk canceling signal generating filters 1206a and 1206b are input to the adders 1203a and 1203b. That is, the crosstalk canceling signal is output to the input side, so the apparatus is a feedback type, and is equivalent to the apparatus shown in Fig. 18. In this case, the apparatus of the fourth embodiment operates in a similar way to the apparatus of the second example in the BACKGROUND IN THE INVENTION section.

As opposed to this, when the switches 1218a and 1218b both turn to feedforward (an FF side in the figure), crosstalk canceling signals generated by crosstalk canceling signal generating filters 1206a and 1206b are input to the adders 1203c and 1203d. That is, the crosstalk canceling signal is output to the output side, so the apparatus is a feedforward type, and equivalent to the apparatus shown in Fig. 17(b). In this case, the apparatus of the fourth embodiment operates in a similar way to the apparatus of the second example in the BACKGROUND IN THE INVENTION section.

In general, the feedback type apparatus has good reproducibility of the low-frequency component. However, as described about the third problem in the prior art, when a loudspeaker included in an acoustic system using the sound imag localization apparatus is small in diameter, the large energy of the low-frequency component causes sound distortion. The feedforward type apparatus has high-pass frequency characteristics which cut off the low-frequency component, and is suited to that system. Accordingly, the sound image localization apparatus of the fourth embodiment switches a feedback or feedforward type apparatus by the switches, so that when a loudspeaker with a large diameter is used, the apparatus operates as a feedback circuit so that good sound quality can be reproduced, while when a loudspeaker with a small diameter is used, the apparatus operates as a feedforward circuit so as to prevent sound distortion.

Thus, the sound image localization apparatus of the fourth embodiment includes the switches 1218a and 1218b, thereby becoming suited to an acoustic system, to which the apparatus is applied, by switching feedback and feedforward.

Fig. 13 is a diagram showing a structure of a second example of the sound image localization apparatus of the fourth embodiment. Fig. 14 is a diagram showing a structure of a third example of the sound image localization apparatus of the fourth embodiment. As shown in Fig. 13, the second example of the apparatus is the apparatus according to the first embodiment that crosstalk cancellation is performed on the input side, and further that switches are added. The third example of the apparatus shown in Fig. 14 comprises the feedback type apparatus in Fig. 18 and, further, switches, as the first example does. While in the first example the switches are disposed at the rear of the crosstalk canceling signal generating filter, i.e., on the output side, in the third example the switches are disposed in front of the filter, i.e., on the input side. The second and third examples of the sound image localization apparatus shown in Figs. 13 and 14 can be suited to an acoustic system by switching feedback and feedforward.

[Embodiment 5]

A sound image localization apparatus in accordance with a fifth embodiment has capability of changing an initial delay in generating a crosstalk canceling signal.

Fig. 15 is a diagram showing a structure of the sound image localization of the fifth embodiment. As shown in the figure, the sound image localization of the fifth embodiment is such that delaying units 1511a to 1511d and switches 1518a and 1518b are added to the feedback type apparatus shown in Fig. 18.

In the situation shown in Fig. 15, the switches 1518a and 1518b are set in a way that the crosstalk canceling signal generating filters 1506a and 1506b output generated signals to the adders 1503b and 1503a without passing the signals through the delay units. In this situation, the sound image localization of the fifth embodiment is equivalent to the apparatus shown in Fig. 18. The sound image localization apparatus of the fifth embodiment with this setting operates in a similar way to the second example in the prior art.

The sound image localization apparatus can use delayed crosstalk canceling signals held in the delaying units 1511b and 1511d, or delayed crosstalk canceling signals held in the delaying units 1511a and 1511c, depending on the setting of the switches 1518a and 1518b, respectively. The sound image localization apparatus of the fifth embodiment with this setting operates in a similar way to that described in the first embodiment, except that the delayed crosstalk canceling signal is used for crosstalk cancellation.

In calculation by the crosstalk canceling signal generating filter, the input signal is multiplied by the coefficient shown in the equation 7-3, representing the ratio of the head related transfer functions SC and SM shown in Fig. 19(b). As is apparent from Fig. 19(b), as the crosstalk path is longer than the main path; there occurs a difference in the times of arrivals of sound signals from two loudspeakers. When the angle of the two loudspeakers is small, the difference in the arrival time is small. When the angle is large, the difference in the arrival time is large. This must be taken into account for sound image localization. In the crosstalk canceling signal generating filter, the arrival time difference is equivalent to the amount of an initial delay. Therefore, in an acoustic system using a sound image localization apparatus, when the fixed amount of an initial delay is used, if the positions of setting up the loudspeakers are changed, crosstalk cancellation is not possibly satisfactory.

In the crosstalk canceling signal generating filter, in cases except for initial delay, the frequency characteristics do not change to a large extent if the angle of two loudspeakers is around 30 to 60 degrees. The change in the angle can be coped with by switching initial delays. The sound image localization apparatus of the fifth embodiment can change the amount of an initial delay in a step-by-step manner by setting of the switches.

As described above, the sound image localization apparatus in accordance with the fifth embodiment further includes the delaying units 1511a to 1511d and the switches 1518a and 1518b, thereby performing a high level of sound image localization by coping with a case where the angle of two loudspeakers are changed in an acoustic system to which the apparatus is applied.

[Embodiment 6]

A sound image localization apparatus in accordance with a sixth embodiment changes a crosstalk canceling signal generating filter.

Fig. 16 is a block diagram showing a structure of the sound image localization apparatus of the sixth embodiment. As shown in the figure, the sound image localization apparatus comprises main-path filters 1607a and 1607b, crosstalk-path filters 1608a and 1608b, adders 1603a to 1603f, crosstalk canceling signal generating filters 1606a and 1606b, delaying units 1611a to 1611d, multipliers 1610x1 to 1610x4, inverting circuits 1631a and 1631b, and switches 1618a to 1618f. The apparatus receives input sound signals through input terminals 1604a to 1604d, and outputs processed signals through output terminals 1605a and 1605b.

The delaying units 1611a and 1611b, the multipliers 1610x1 and 1610x2, and the adder 1603c constitute a first FIR filter having two taps. The delaying units 1611c and 1611d, the multipliers 1610x3 and 1610x4, and the adder 1603d constitute a second FIR filter having two taps. Either filter functions as a crosstalk canceling signal generating filter. The switches 1618a to 1618f are switched depending on the distance between two loudspeakers of an acoustic system using the sound image localization apparatus.

The main-path filters 1607a and 1607b, the crosstalk-path filters 1608a and 1608b, the adders 1603a to 1603d, and the crosstalk canceling signal generating filters 1606a and 1606b are similar to those of the feedback type sound image localization apparatus shown in Figs. 1(a) and 1(b).

The operation of the sound image localization apparatus of the sixth embodiment will be described as to when the distance between two loudspeakers is wide or narrow.

At first, when the distance between two loudspeakers is wide, the switches 1618a, 1618b, 1618e, and 1618f are set to respective W sides, while the switches 1618c and 1618d are set to be released. This is the situation shown in the figure. In this case, sound signals input through the input terminals 1604c and 1604d are output to the output terminals 1605a and 1606b, passing through the sound image localization apparatus of the sixth embodiment.

Signals input through the input terminals 1604a and 1604b are subjected to directional localization, and then, input through the switches 1618a and 1618b to the crosstalk canceling signal generating filters 1606a and 1606b. Thereafter, signals output from the first and second FIR filters each having two taps are not used because the switches 1618c and 1618d are released. Therefore, the operation of the apparatus is equivalent to that of the feedback type sound image localization apparatus shown in Fig. 18.

As opposed to this, when the distance between the two loudspeakers is narrow, the switches 1618a, 1618b, 1618e, and 1618f are set to N sides, while the switches 1618c and 1618d are closed. Thus, signals after subjected to directional localization are processed by the first and second FIR filters each having two taps, and then, input through the switches 1618c and 1618d to the adders 1603a and 1603b. That is, the first and second FIR filters are used for crosstalk cancellation.

On the other hand, the phases of sound signals input through the input terminals 1604c and 1604d are inverted by the inverting circuits 1631a and 1631b, and then, input through the switches 1618a and 1618b to the filters 1606a and 1606b. The filters 1606a and 1606b generate signals based on the phase inverted signals, and output the generated signals to the adders 1603a and 1603b.

In this case, the channels to the adders 1603a and 1603b function as main paths due to the switches 1618e and 1618f, while the filters 1606a and 1606b generate crosstalk canceling signals. This is effective processing when a sound image to be localized at the front position and a sound image to be localized at an arbitrary position (at the side or the rear) coexist in a sound signal. When the distance between two loudspeakers is narrow, if a sound image to be localized at the front is extended further outward, stereophony increases.

That is, in the apparatus of the sixth embodiment, a sound signal of the sound image to be localized at the arbitrary position is input through the input terminals 1604a and 1604b, while a sound signal of the sound image to be localized at the front position is input through the input terminals 1604c and 1604d. When the distance between two loudspeakers is wide, the sound image to be localized at the front position is output as it is, while the sound image to be localized at the arbitrary position is subjected to crosstalk cancellation similar to that in the first embodiment. When the distance between the two loudspeakers is narrow, a crosstalk canceling signal is generated for the sound image to be localized at the front position to extend the sound image outward. On the other hand, for the sound image to be localized at the arbitrary position, the crosstalk canceling signal generating filter used for sound localization multiplies an input signal by the coefficient shown in the equation 7-3, representing the ratio of the head related transfer functions SC and SM shown in Fig. 19(b). Because the distance between the two loudspeakers is narrow, the ratio is small, so that it is possible to use a filter having a small number of taps. Therefore, the filter having two taps is used.

As described above, the sound image localization apparatus of the sixth embodiment comprises the conventional feedback type sound image localization apparatus and, further, the FIR filters with two taps comprising the delaying units 1611a to 1611d, the multipliers 1610x1 to 1610x4, and the adders 1603c to 1603d, the switches 1618a to 1618d, and the inverting circuits 1631a and 1631b, whereby when the distance between two loudspeakers is wide, the feed-

back sound localization similar to that in the first embodiment is performed, while when the distance between two loudspeakers is narrow, the outward extension of a sound image to be localized at the front is performed as well as the feedback sound localization.

Note that although the apparatus of the sixth embodiment is based on the feedback type sound image localization apparatus shown in Fig. 18, the apparatus of the sixth embodiment can be based on the feedforward type apparatus shown in Fig. 17(b) or the apparatus of the first embodiment shown in Fig. 1(b).

Claims

1. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for generating a crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
   direction localizing means for localizing the direction of a virtual sound source position by processing the signal subjected to crosstalk cancellation in said crosstalk canceling means.

2. The sound image localization apparatus of claim 1 wherein

   said crosstalk canceling means comprise first and second crosstalk canceling signal generating filters, and first and second adders, said first adder adding a first sound signal and a signal generated by said second crosstalk canceling signal generating filter, and said second adder adding a second sound signal and a signal generated by said first crosstalk canceling signal generating filter;
   said direction localizing means comprise first and second main-path filters, first and second crosstalk-path filters, and first and second adders, said first adder adding a signal processed by said first main-path filter and a signal processed by said second crosstalk-path filter, and said second adder adding a signal processed by said second main-path filter and a signal processed by said first crosstalk-path filter.

3. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for including a comb filter to generate the crosstalk canceling signal, and performing crosstalk cancellation using the crosstalk canceling signal; and
   direction localizing means for localizing the direction of a virtual sound source position.

4. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means for generating a crosstalk canceling signal generated at a certain time, holding the crosstalk canceling signal, delaying the crosstalk canceling signal held, holding the plurality of crosstalk canceling signals delayed, and multiplying some of the plurality of crosstalk canceling signals held, by a predetermined coefficient to generate the crosstalk canceling signal at a time following the certain time; and
   direction localizing means for localizing the direction of a virtual sound source position.

5. The sound image localization apparatus of any of claim 3 and claim 4 wherein

   said apparatus further comprises a low-pass filter processing a signal input to or output from said crosstalk canceling means.

6. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a switch switching the crosstalk canceling signal generated by said crosstalk canceling signal generating filter to the output side of said crosstalk canceling signal generating filter or to the input side of said crosstalk canceling signal generating filter; and
   direction localizing means for localizing the direction of a virtual sound source position.

7. A sound image localization apparatus receiving a sound signal, performing signal processing to the sound signal, localizing a virtual sound image, and outputting a sound image localization signal, said apparatus comprising:

   crosstalk canceling means comprising a crosstalk canceling signal generating filter generating a crosstalk canceling signal, and a delaying unit delaying a signal input to or output from said crosstalk canceling signal generating filter by various times; and
   direction localizing means for localizing the direction of a virtual sound source position.

8. A sound image localization apparatus receiving an input sound signal to be localized in a first direction, and an input sound signal to be localized in a second direction, performing signal processing to the input sound signals, localizing virtual sound images, and outputting sound image localization signals, said apparatus comprising:

   crosstalk canceling means comprising a first filter, a second filter, and a switch switching first and second modes; in the first mode said first filter functioning as a filter generating the crosstalk canceling signal, and in the second mode said second filter functioning as a filter generating the crosstalk canceling signal while said first filter functioning as a filter localizing the second direction; and
   direction localizing means for localizing the direction of a virtual sound source position.

Fig.1 (a)

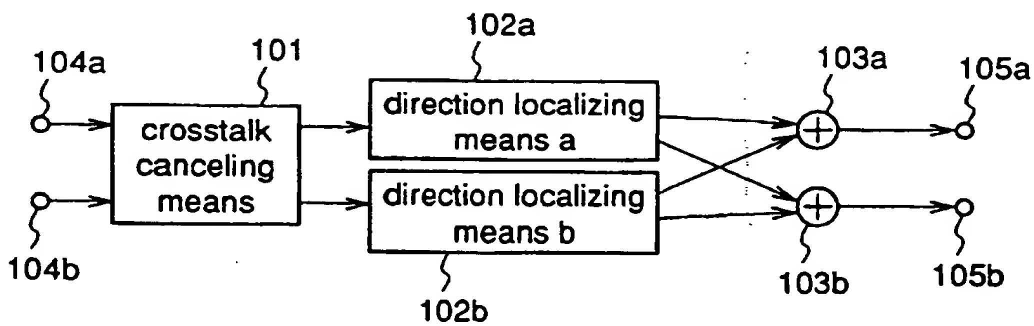
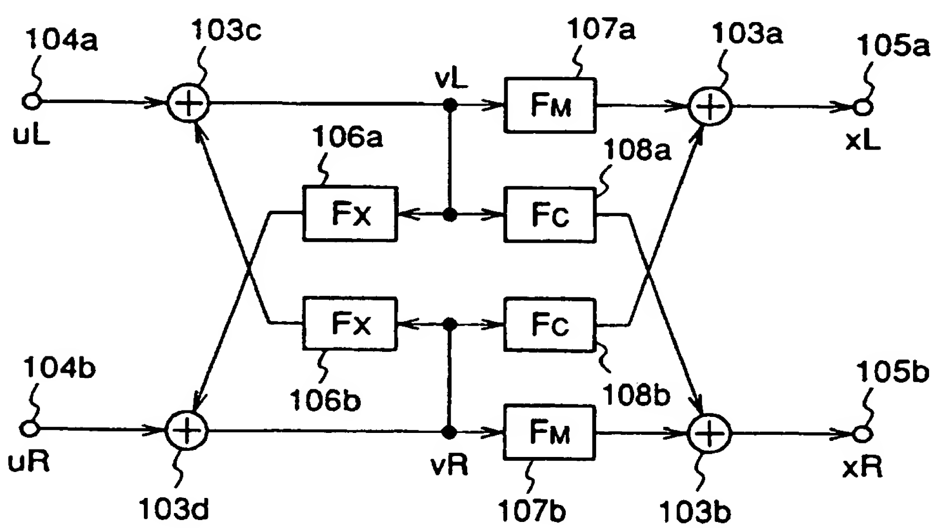

104a
101
102a
103a
105a
crosstalk canceling means
direction localizing means a
direction localizing means b
104b
102b
103b
105b

Fig.1 (b)


104a
103c
107a
103a
105a
uL
vL
FM
xL
106a
108a
Fx
Fc
Fx
Fc
104b
106b
108b
105b
FM
uR
vR
xR
103d
107b
103b

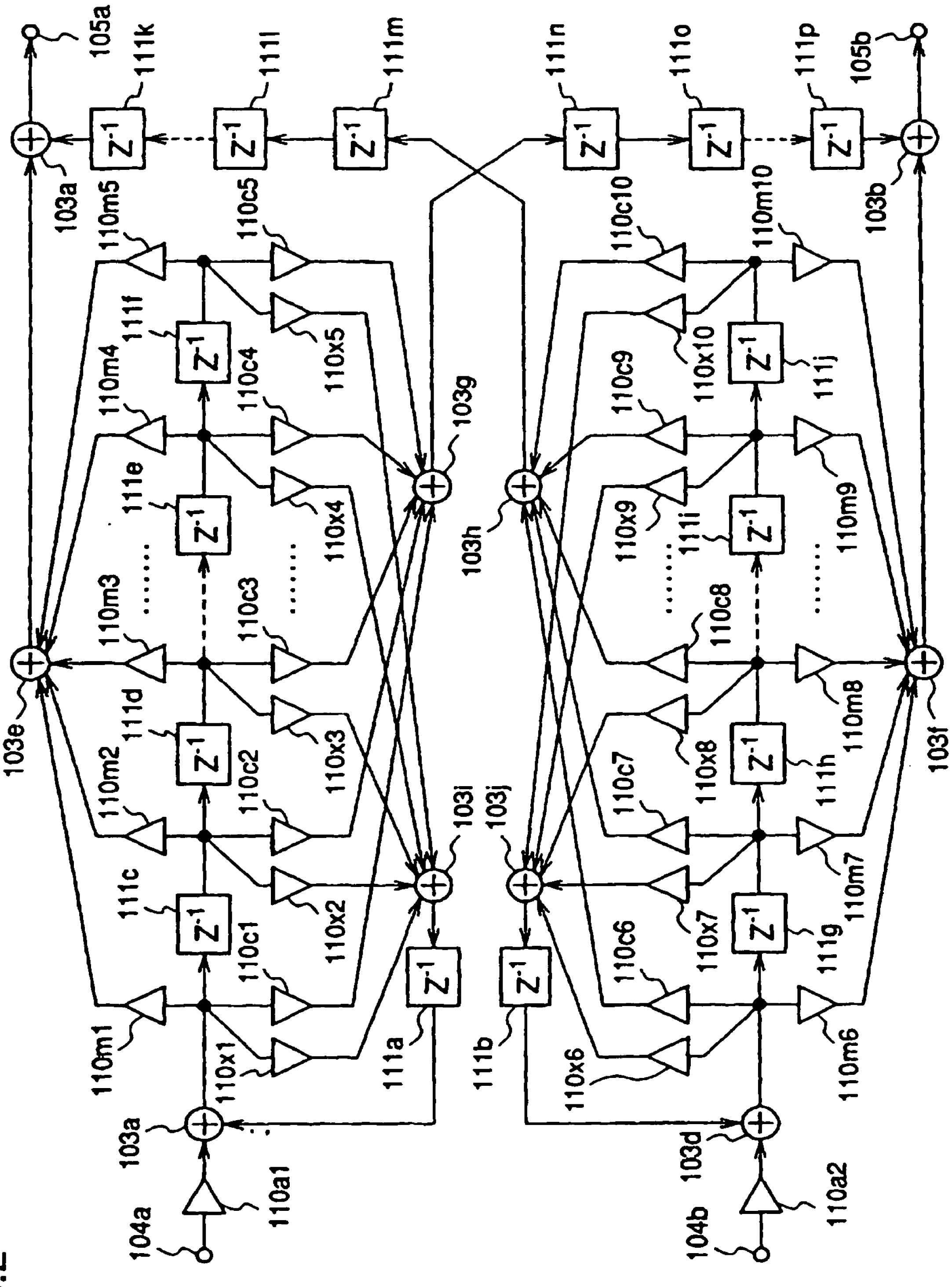

105a
111k
111l
111m
111n
111o
111p
105b
103a
103b
110m5
110c5
110c10
110m10
111f
110m4
110x5
110c4
103g
111e
110x4
110c9
110x10
111j
103h
110m3
110c3
110x9
111i
110m9
103e
111d
110c8
110x3
110x8
110m2
110c2
103i
103j
110c7
111h
103f
110m8
111c
110x2
110c1
110c6
110x7
111g
110m7
110m1
110x1
111a
111b
110x6
110m6
103a
103d
104a
110a1
104b
110a2

Fig.2

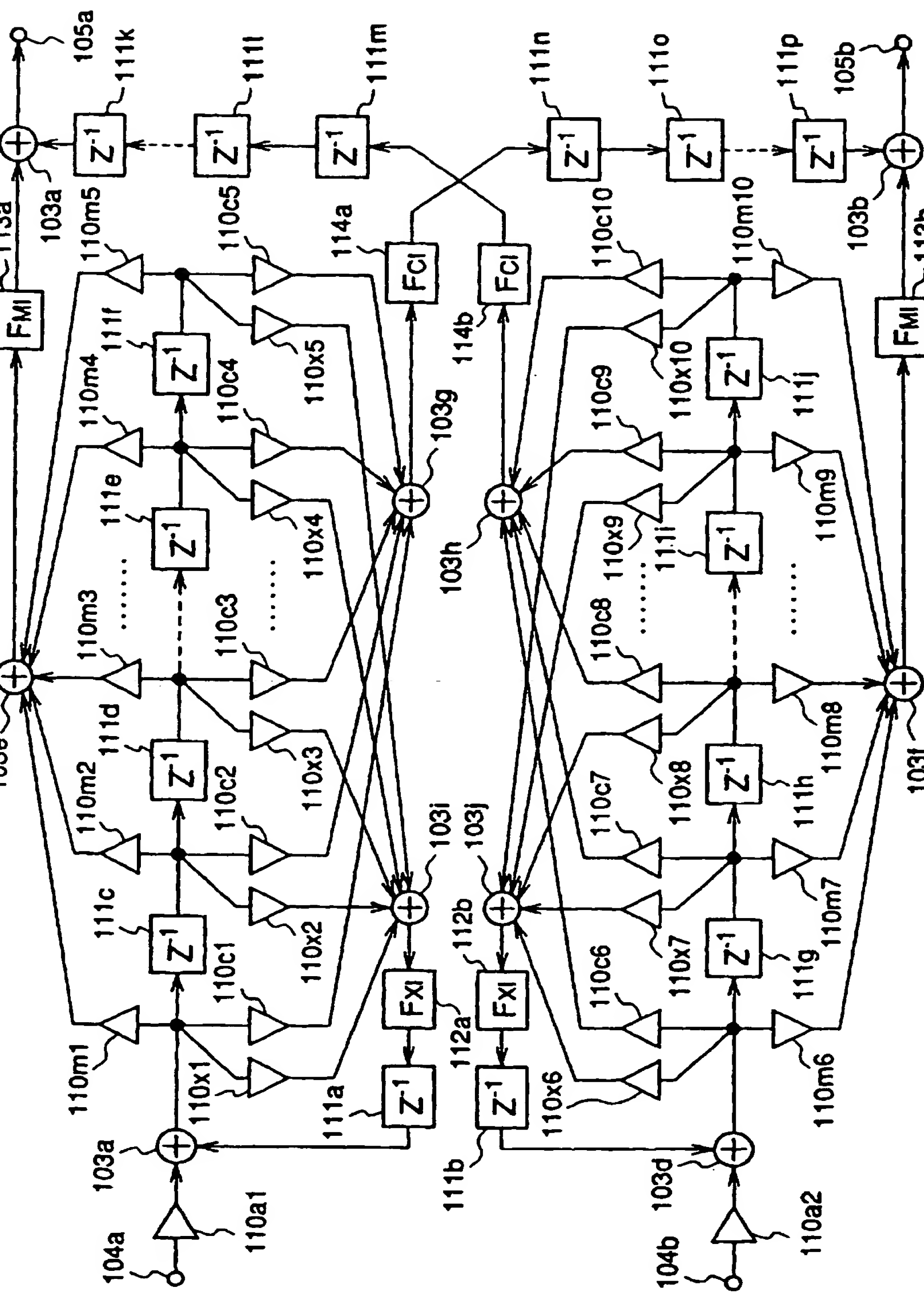
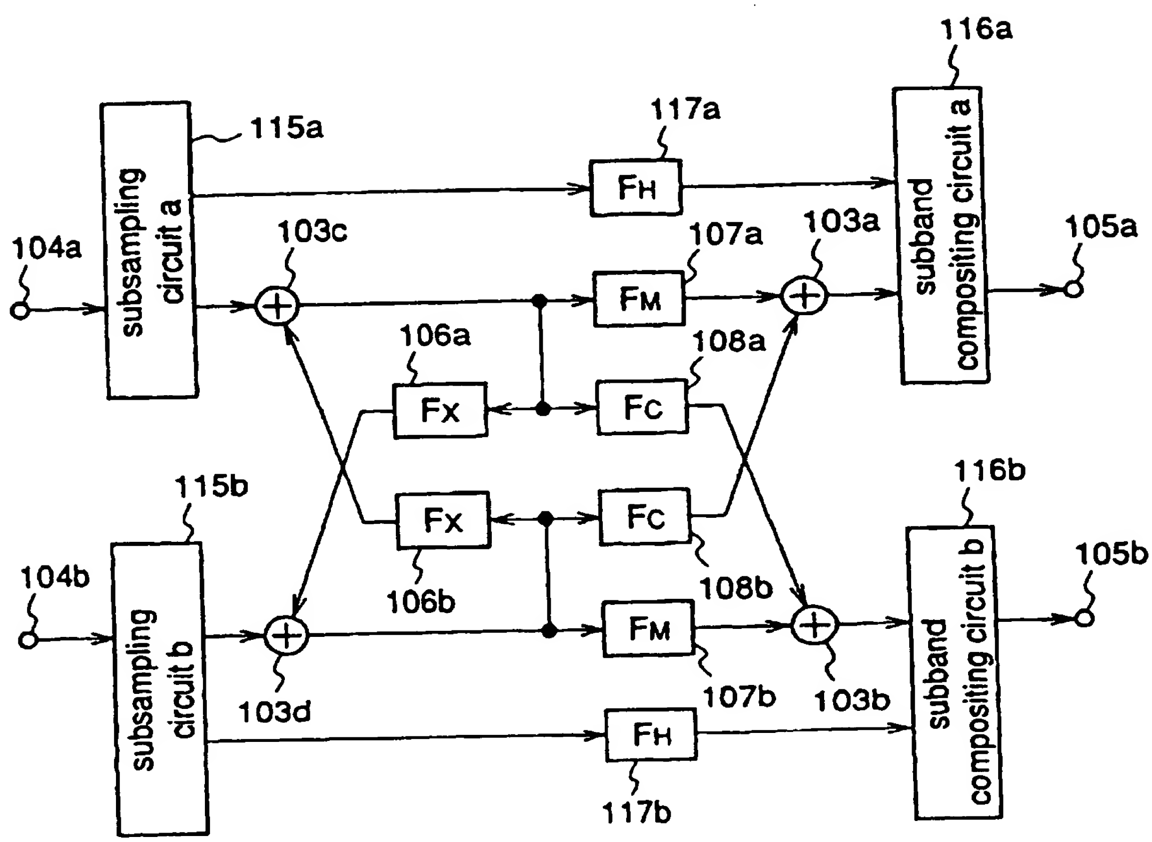

104a
110a1
103a
110m1
110x1
110c1
111a
111c
110x2
110m2
110c2
103i
111d
110x3
103e
110m3
110c3
111e
110x4
110m4
110c4
103g
111f
110x5
110m5
110c5
114a
113a
103a
111k
105a
111l
111m
104b
110a2
103d
111b
110x6
110m6
110c6
111g
112a
112b
110x7
110m7
110c7
103j
111h
110x8
110m8
103f
110c8
111i
110x9
110m9
103h
110c9
111j
110x10
110m10
110c10
114b
113b
103b
111n
111o
111p
105b
FXI
FXI
FCI
FCI
FMI
FMI
Z^{-1}

Fig.3

Fig.4


116a
117a
115a
subsampling circuit a
FH
subband compositing circuit a
104a
103c
107a
103a
105a
FM
106a
108a
Fx
Fc
115b
Fx
Fc
116b
104b
106b
108b
105b
subsampling circuit b
FM
subband compositing circuit b
103d
107b
103b
FH
117b

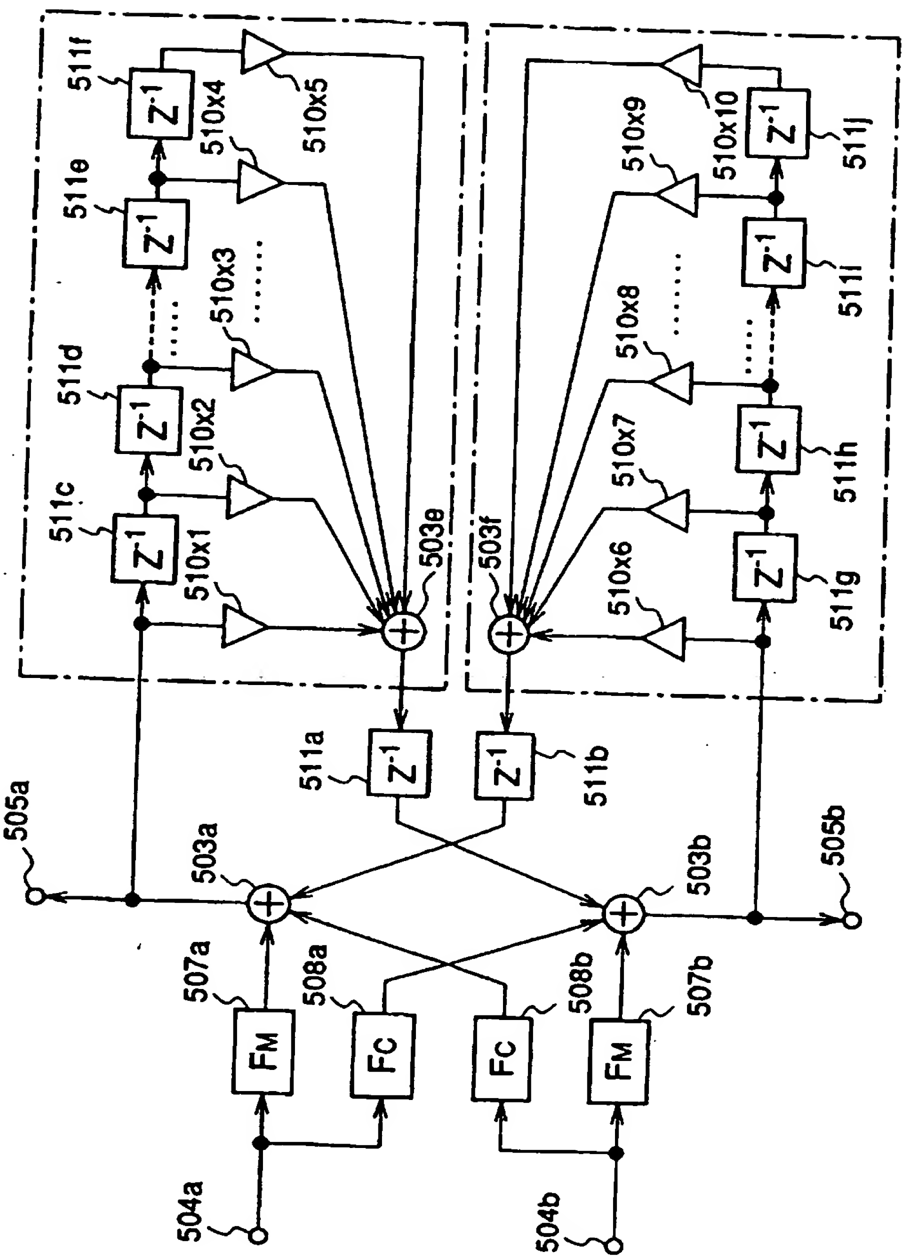

504a
504b
507a
507b
508a
508b
FM
Fc
Fc
FM
503a
503b
505a
505b
511a
511b
503e
503f
511c
511d
511e
511f
511g
511h
511i
511j
510x1
510x2
510x3
510x4
510x5
510x6
510x7
510x8
510x9
510x10

Fig.5

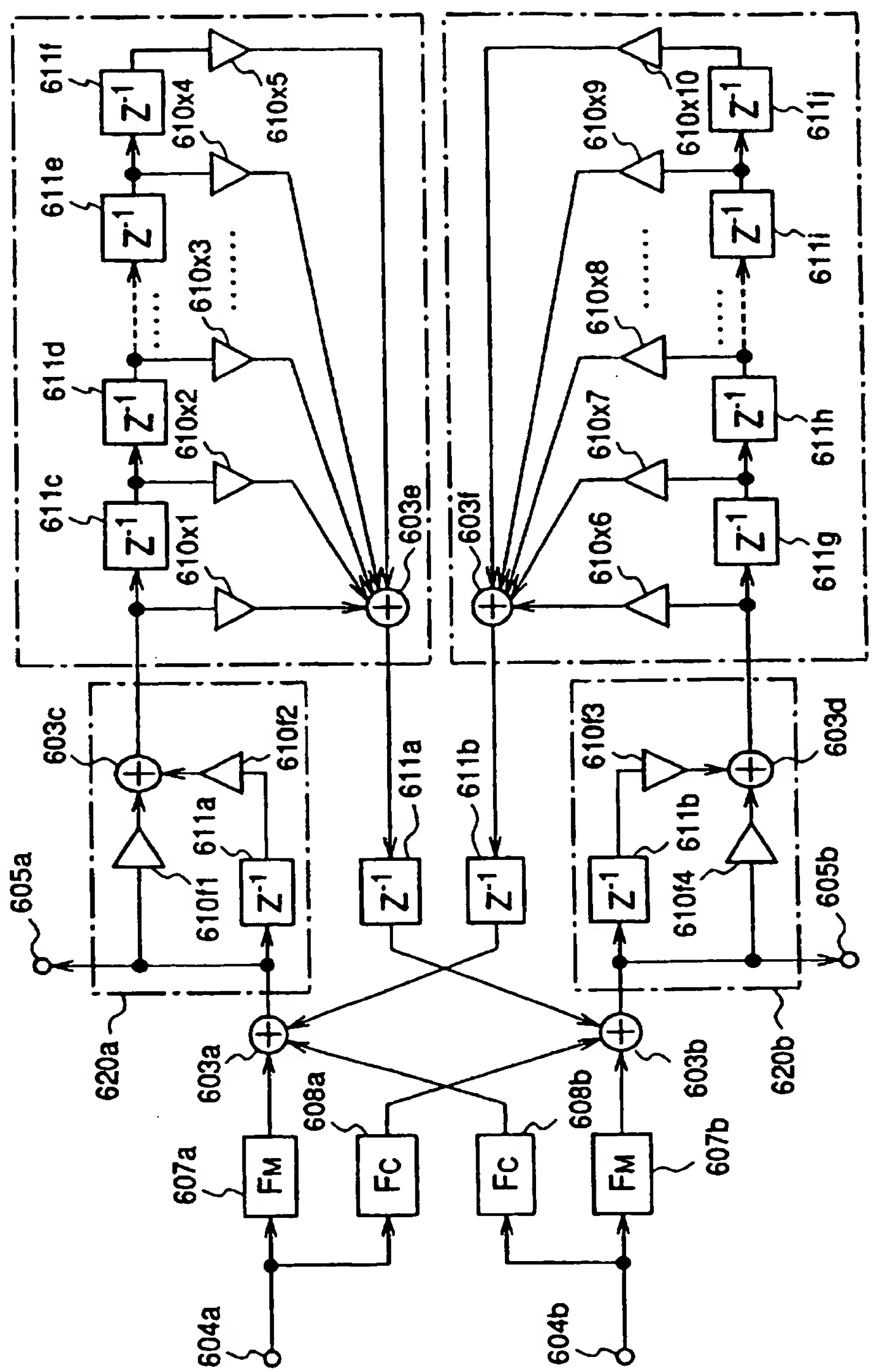

604a
604b
607a
607b
FM
FM
Fc
Fc
608a
608b
603a
603b
603c
603d
603e
603f
605a
605b
620a
620b
610f1
610f2
610f3
610f4
611a
611b
Z-1
610x1
610x2
610x3
610x4
610x5
610x6
610x7
610x8
610x9
610x10
611c
611d
611e
611f
611g
611h
611i
611j

Fig.6

Fig.7 (a)

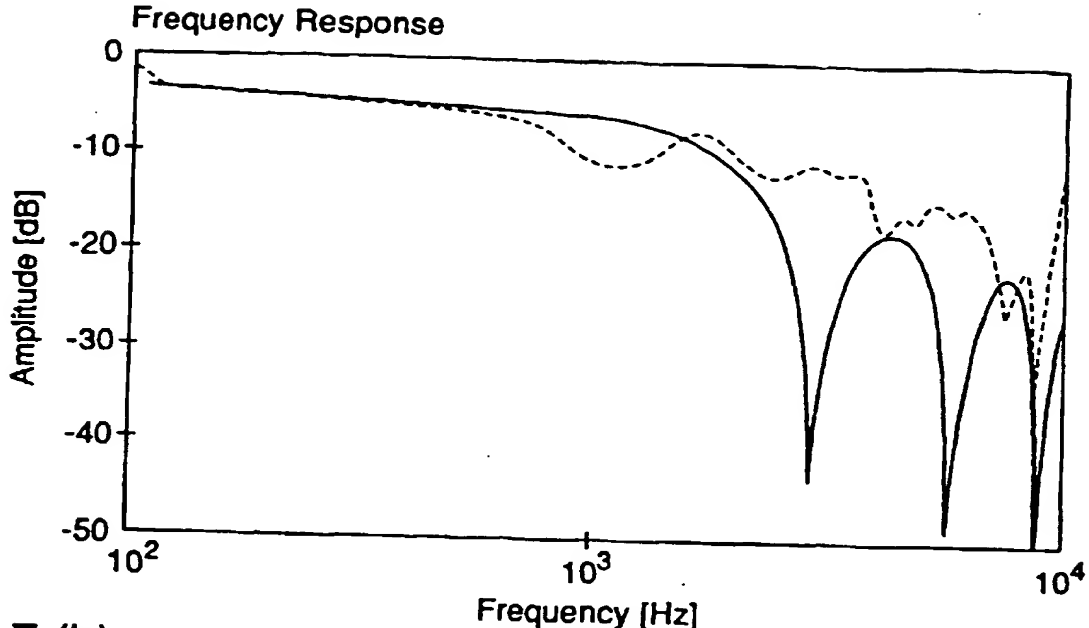

Frequency Response
0
-10
-20
-30
-40
-50
Amplitude [dB]
10^2
10^3
10^4
Frequency [Hz]

Fig.7 (b)

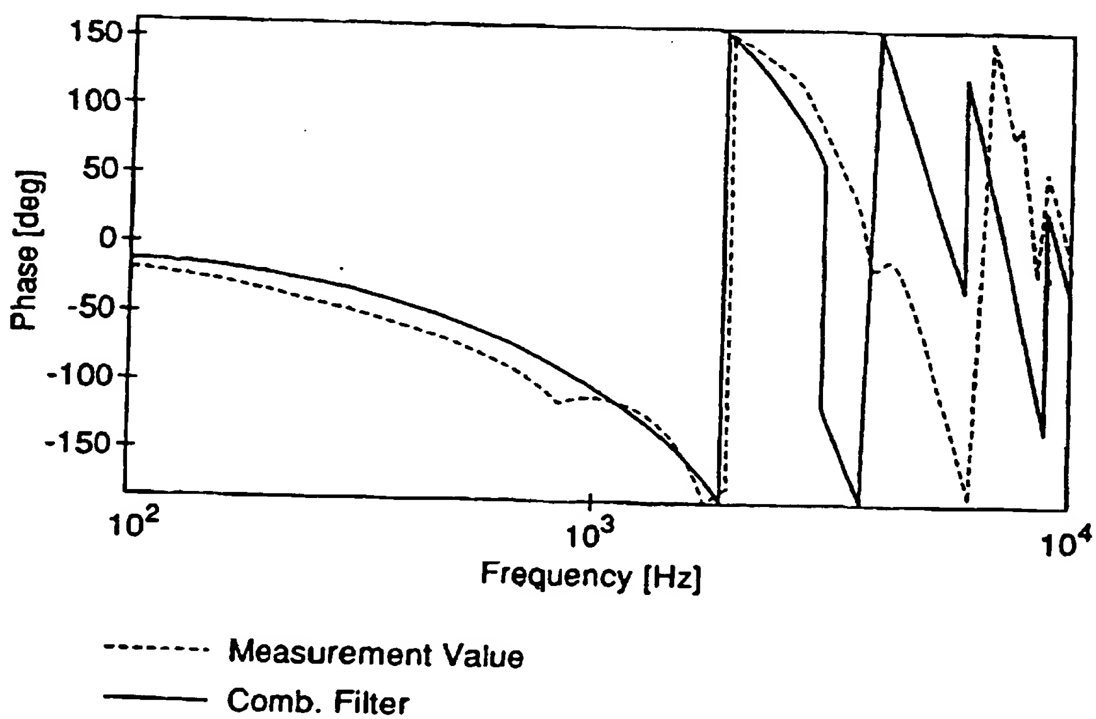
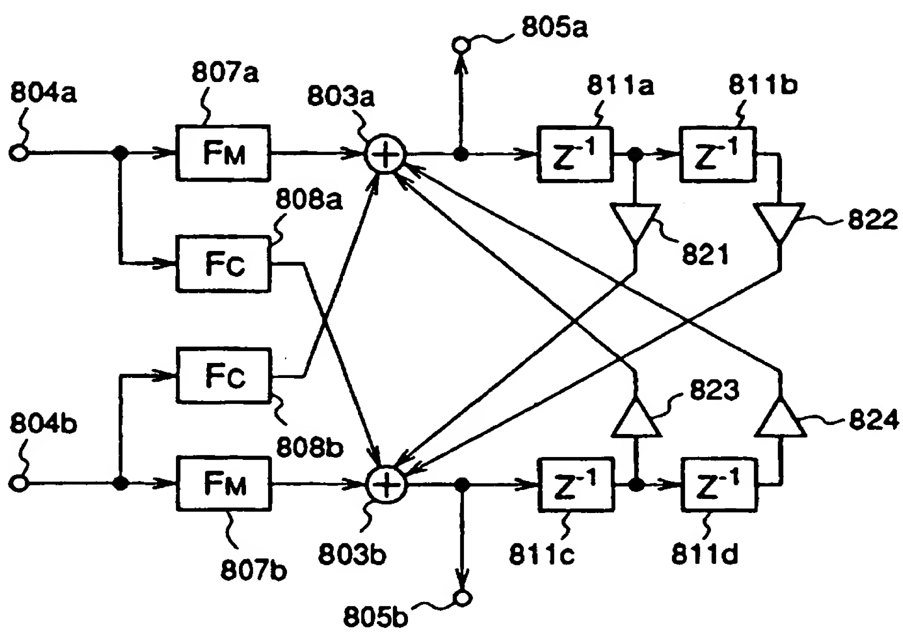

150
100
50
0
-50
-100
-150
Phase [deg]
10^2
10^3
10^4
Frequency [Hz]
Measurement Value
Comb. Filter

Fig.8


805a
807a
804a
803a
811a
811b
FM
Z-1
Z-1
808a
822
821
FC
FC
823
804b
824
808b
FM
Z-1
Z-1
807b
803b
811c
811d
805b

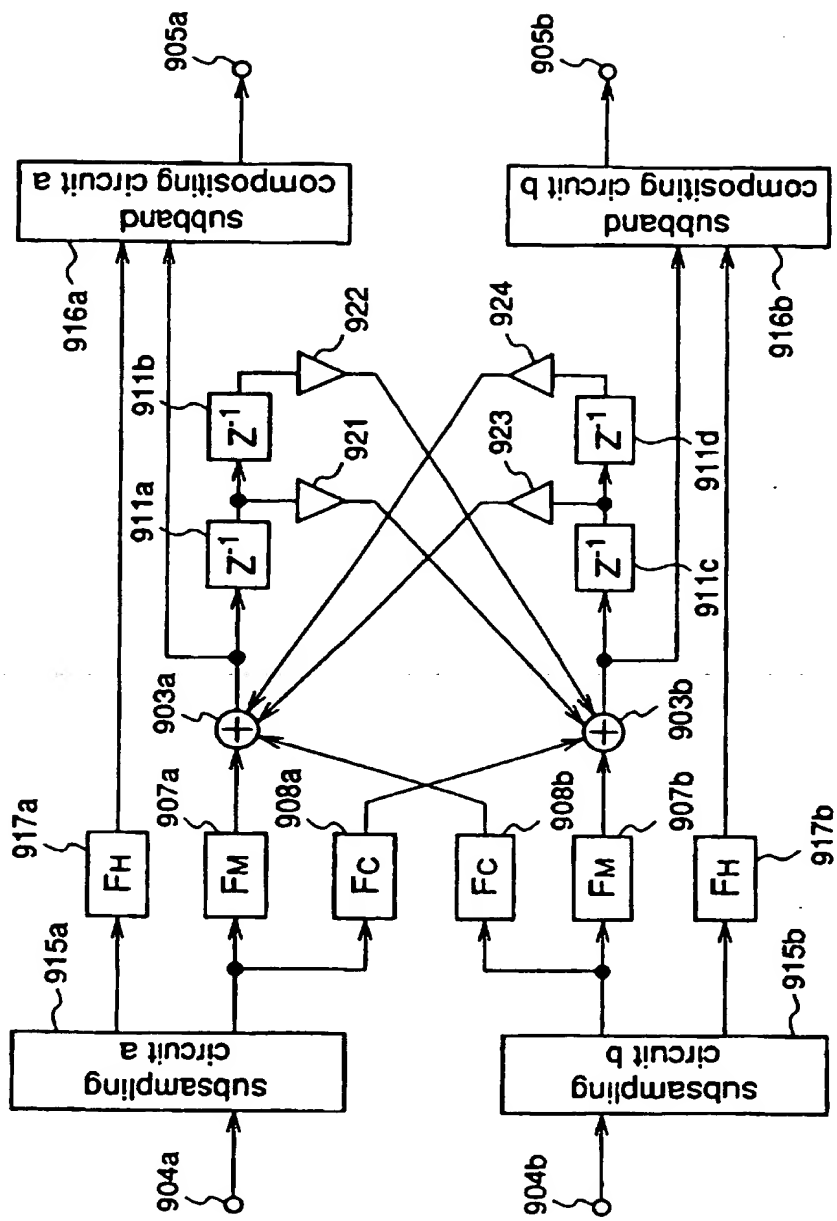

subband compositing circuit a
subband compositing circuit b
subsampling circuit a
subsampling circuit b
905a
905b
904a
904b
916a
916b
915a
915b
917a
917b
907a
907b
908a
908b
903a
903b
911a
911b
911c
911d
921
922
923
924
FH
FM
FC
FC
FM
FH
Z^{-1}
Z^{-1}
Z^{-1}
Z^{-1}

Fig.9

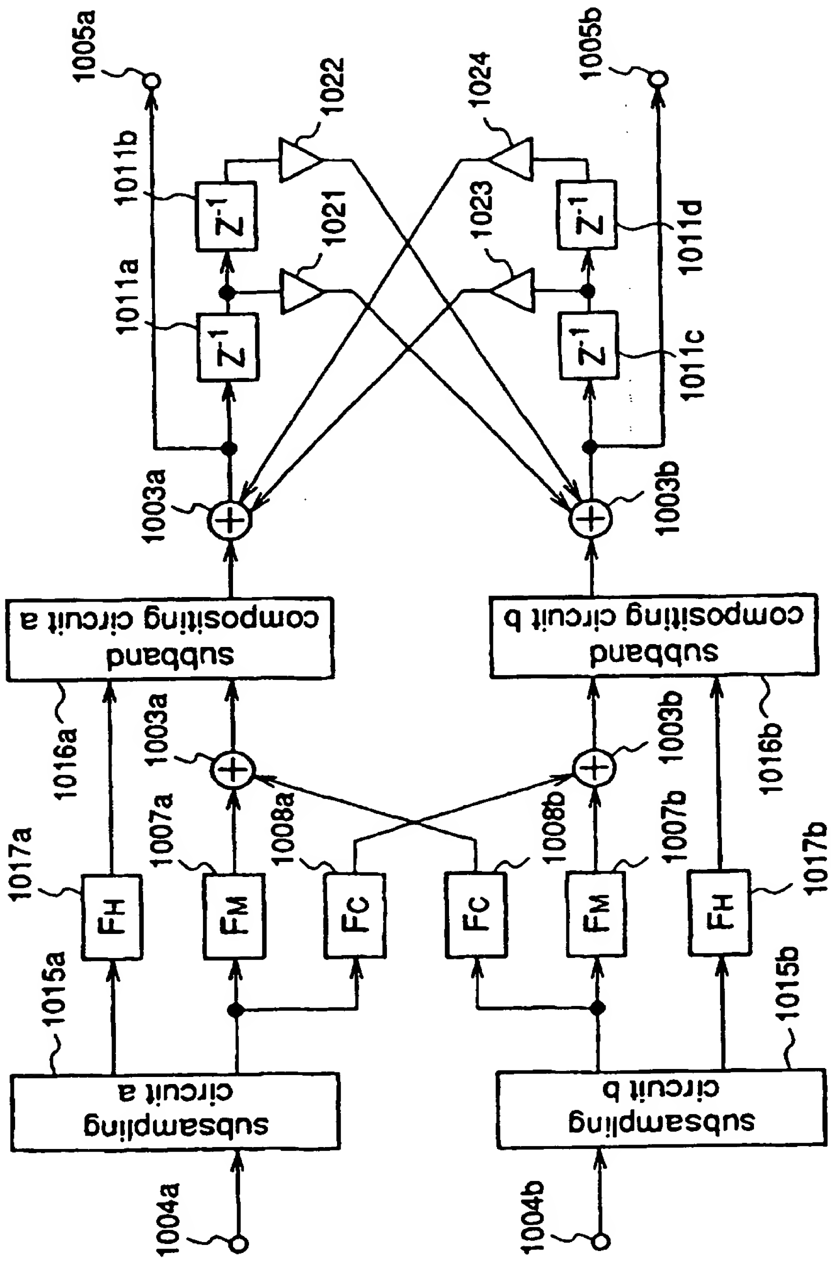

1005a
1005b
1022
1024
1011b
1021
1023
1011a
1011d
1011c
Z-1
1003a
1003b
subband compositing circuit a
subband compositing circuit b
1016a
1016b
1007a
1008a
1008b
1007b
1017a
1017b
FH
FM
FC
1015a
1015b
subsampling circuit a
subsampling circuit b
1004a
1004b

Fig.10

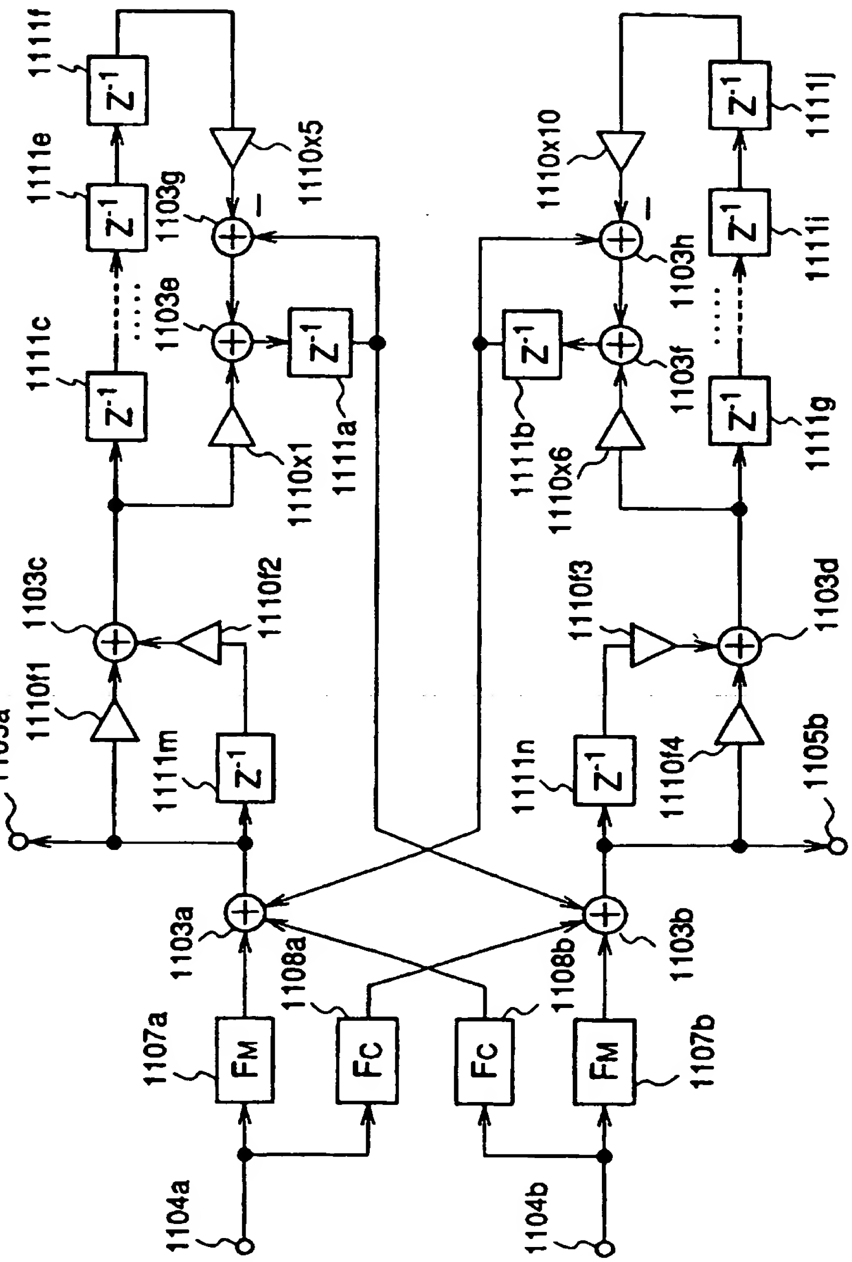

1104a
1104b
1107a
1107b
FM
FM
FC
FC
1108a
1108b
1103a
1103b
1105a
1105b
1111m
1111n
Z-1
1110f1
1110f2
1110f3
1110f4
1103c
1103d
1110x1
1110x5
1110x6
1110x10
1111a
1111b
1111c
1111e
1111f
1111g
1111i
1111j
1103e
1103f
1103g
1103h

Fig.11

Fig.12

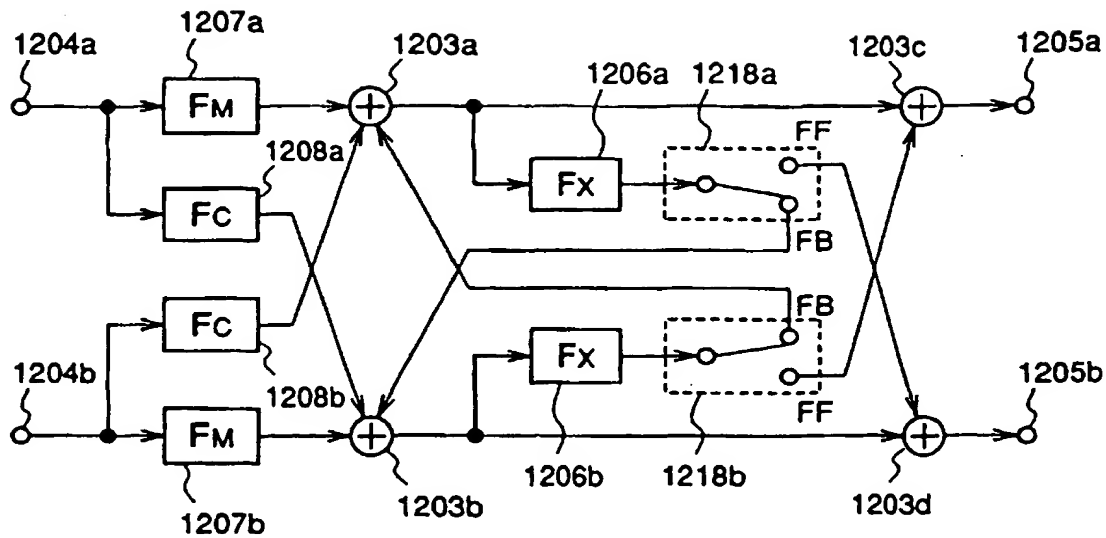

1204a
1207a
1203a
1203c
1205a
1206a
1218a
FM
FF
1208a
Fx
Fc
FB
FB
Fc
Fx
1204b
1205b
1208b
FF
FM
1206b
1218b
1203b
1203d
1207b

Fig.13

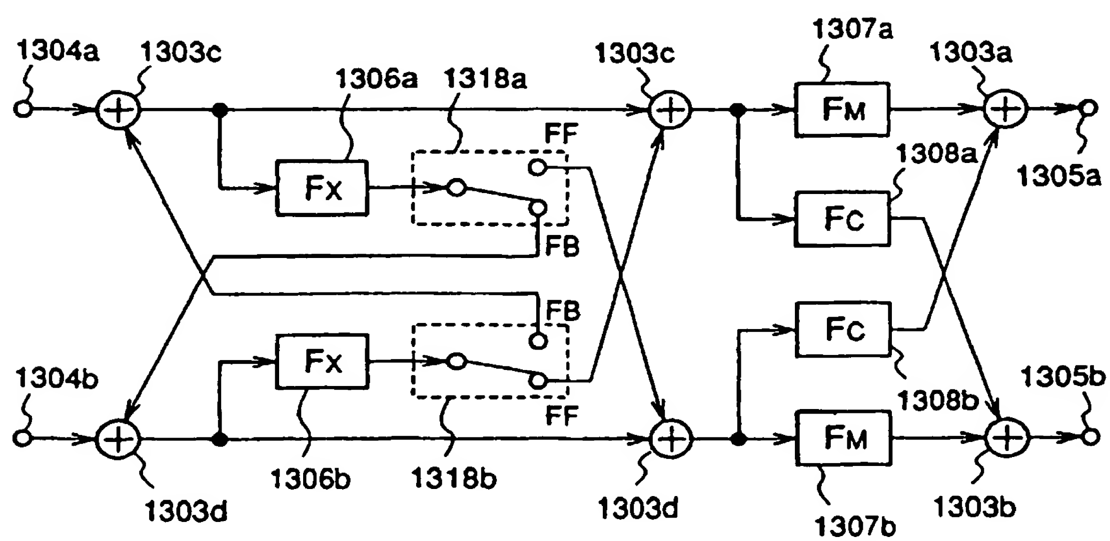

1307a
1304a
1303c
1303c
1303a
1306a
1318a
FM
FF
1308a
Fx
1305a
FB
Fc
FB
Fc
Fx
1304b
1305b
FF
1308b
FM
1306b
1318b
1303d
1303d
1303b
1307b

Fig.14

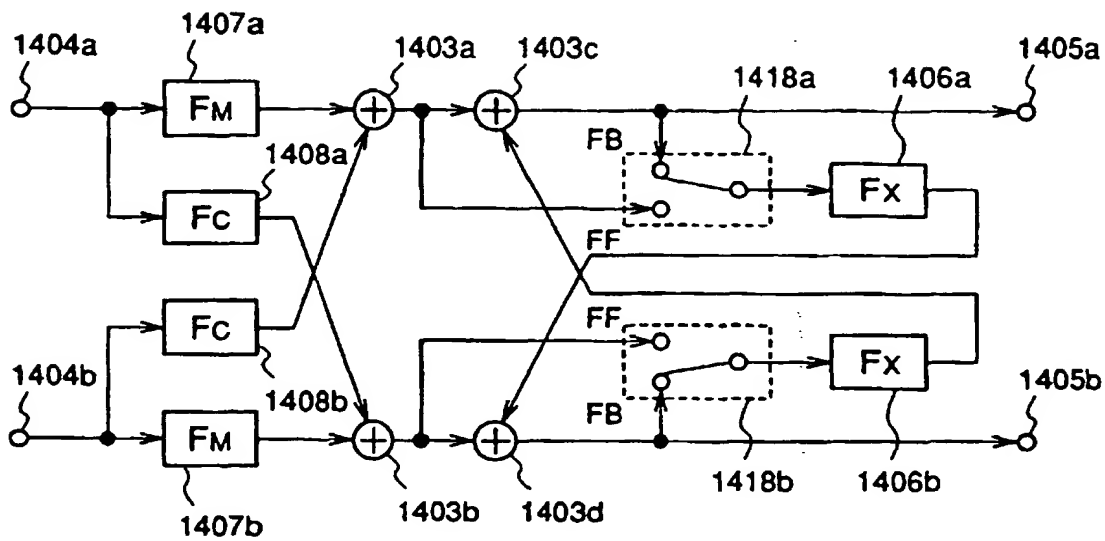
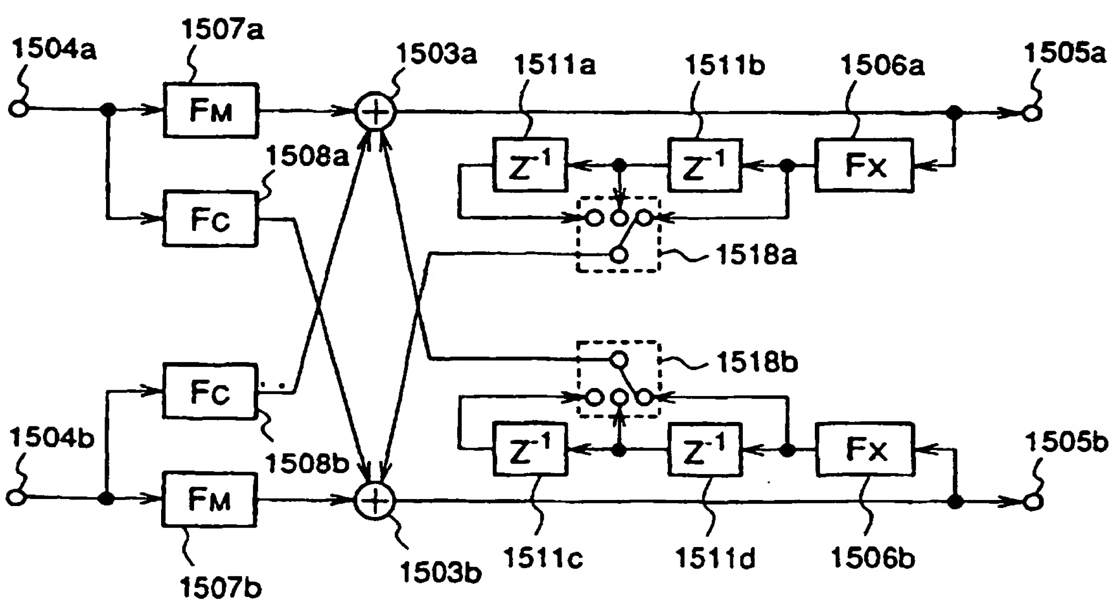

1404a
1407a
1403a
1403c
1405a
1418a
1406a
FM
FB
1408a
Fc
Fx
FF
Fc
FF
Fx
1404b
1405b
1408b
FB
FM
1418b
1406b
1403b
1403d
1407b

Fig.15


1504a
1507a
1503a
1511a
1511b
1506a
1505a
FM
1508a
Z^{-1}
Z^{-1}
Fx
Fc
1518a
1518b
Fc
1504b
1508b
Z^{-1}
Z^{-1}
Fx
1505b
FM
1503b
1511c
1511d
1506b
1507b

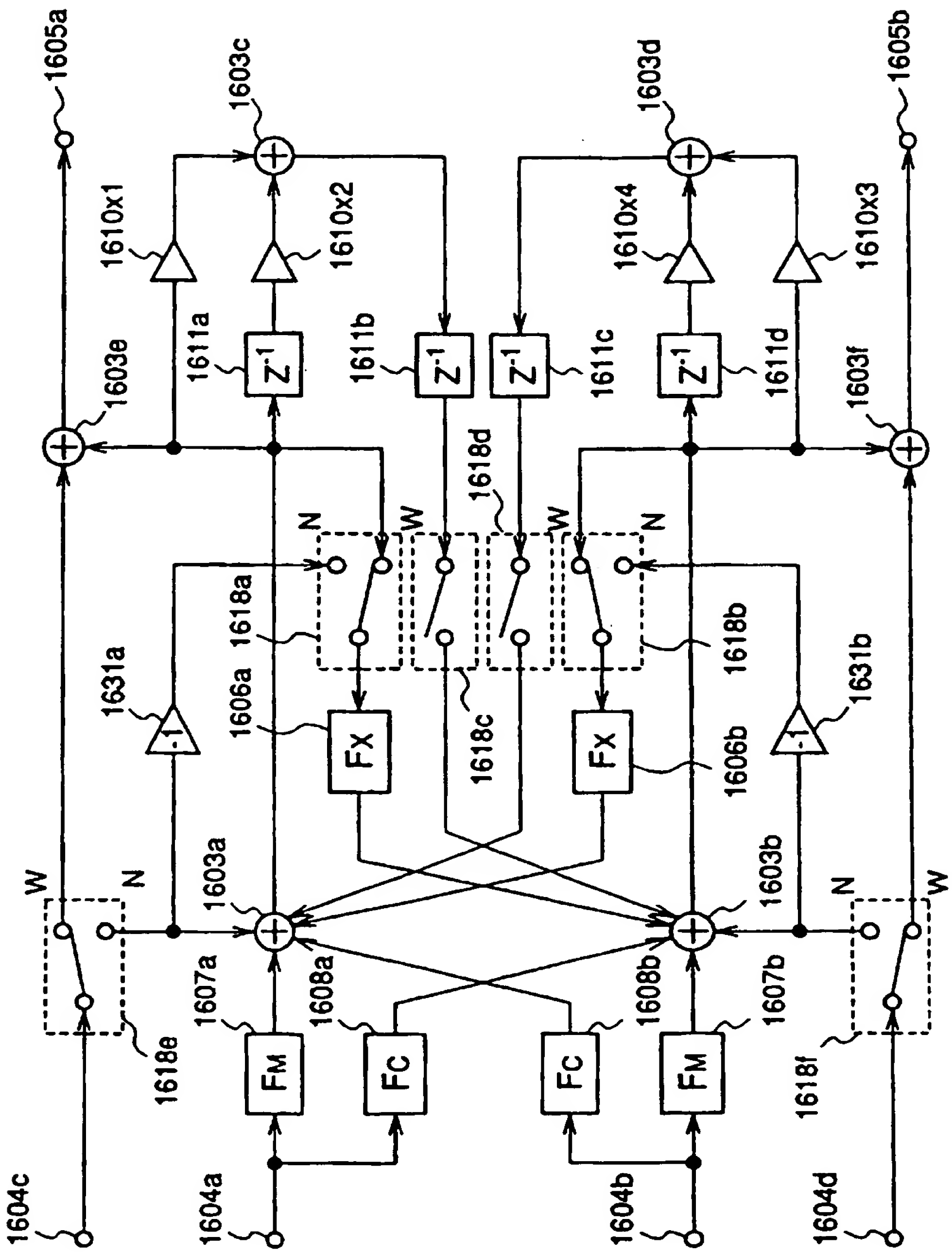

1605a
1603c
1603d
1605b
1610x1
1610x2
1610x4
1610x3
1603e
1611a
1611b
1611c
1611d
1603f
Z^{-1}
Z^{-1}
Z^{-1}
Z^{-1}
1618d
N
W
W
N
1618a
1618b
1631a
1631b
1606a
1618c
1606b
FX
FX
W
N
N
W
1603a
1603b
1607a
1608a
1608b
1607b
1618e
1618f
FM
FC
FC
FM
1604c
1604a
1604b
1604d

Fig.16

Prior Art

Fig.17 (a)

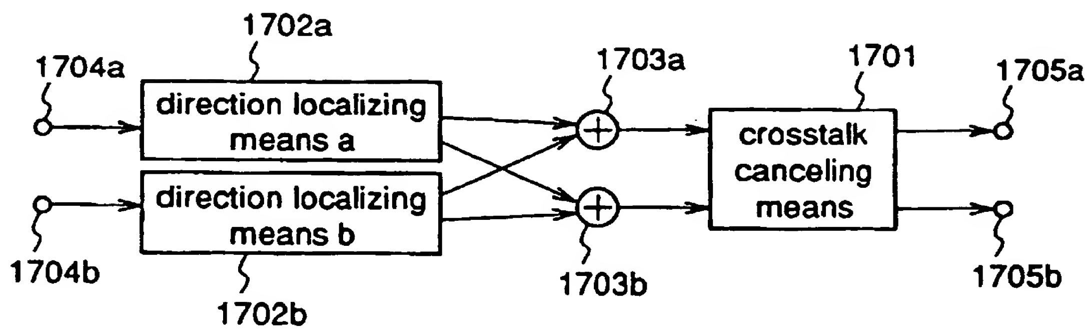


Fig.17 (b)

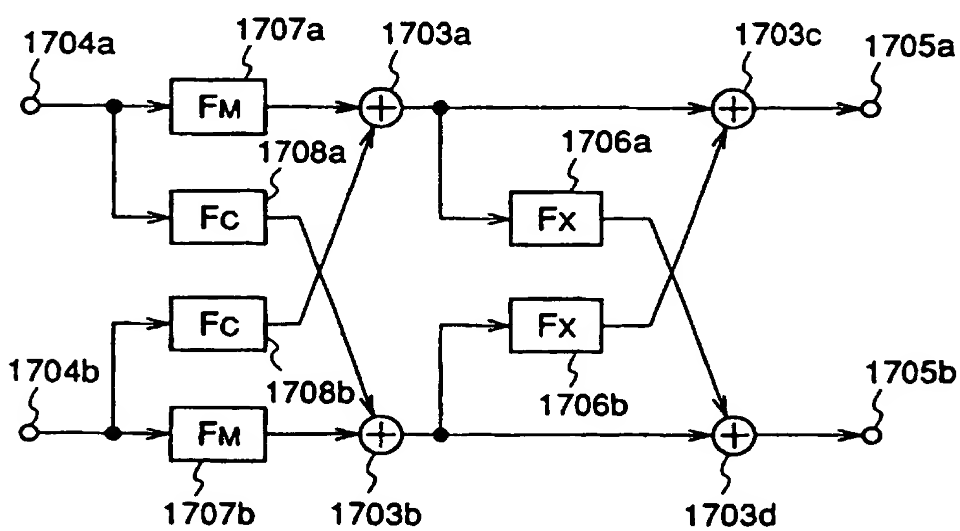
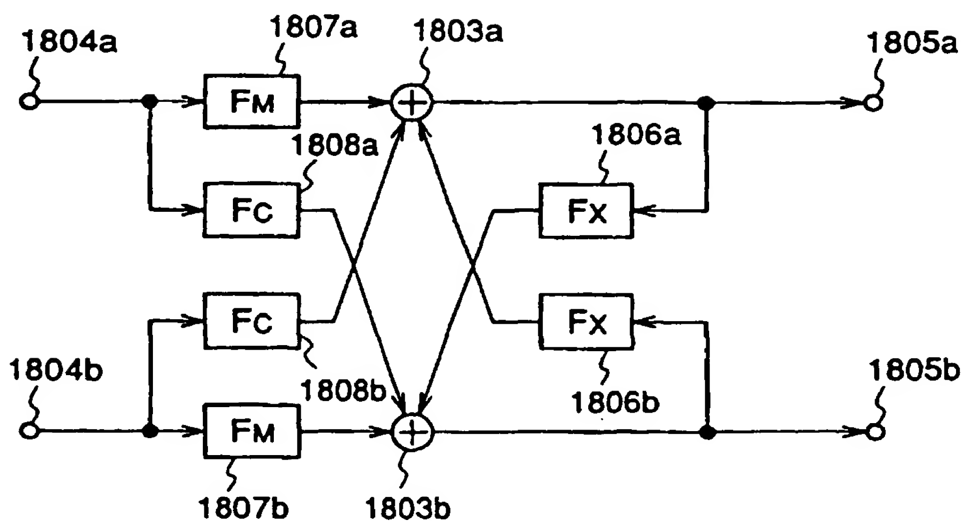


Fig.18 Prior Art



Prior Art

Fig.19 (a)

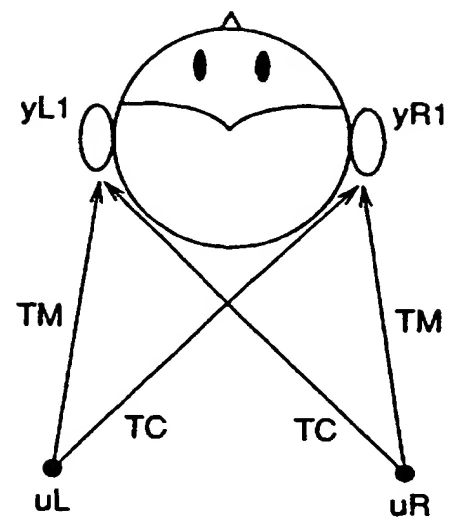


Fig.19 (b)